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THEORY AND PRACTICAL ATTAINMENTS IN THE DESIGN AND USE OF RADIO DIRECTION FINDING APPARATUS USING CLOSED COIL ANTENNAS.*

BY

A. S. BLATTERMAN,

Captain, Signal Corps, U. S. Army.

INTRODUCTION.

It is a common enough experience in radio stations to be able to hear signals on a sensitve receiving set when the antenna is disconnected entirely from the apparatus. In such cases the tuning coils of the receiver pick up energy directly and the signal produced depends upon the electromotive force induced in the coils by the alternating magnetic flux component of the passing wave which threads through the windings. Another familiar example of coil reception is afforded by the ordinary wavemetre. Such small coils as these are, of course, extremely poor receivers; but the fact that they do receive enough energy at all over distances of the order of a number of wave-lengths at once leads to speculation as to the possibility of using larger coils especially designed for the efficient reception of signals.

In considering this problem the average engineer would at once conclude that the coils should be given large area, many turns and low resistance. The questions that he would probably not be able to answer, however, would be—How large shall the

* Communicated by Maj.-Gen. George Owen Squier.

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area be, and how many turns. As a matter of fact, his first conclusions would only be partly correct, for while it is, of course, desirable to keep the resistance down to the lowest possible value, it has been found that the size of the coil and the number of turns cannot be illimitably increased without seriously reducing the efficiency. Actually, there exists for every wave-length a certain set of optimum dimensions giving maximum response at the detector. These facts have not been generally recognized heretofore, and although closed coil or loop receivers have been in practical use for the reception of signals over long distances for several years, they have not, up to the present time, been built according to completely rational designs. The proper size of the loop, the number of turns, the size and kind of wire and the spacing of same has been largely a matter of good technical judgment.

In addition to the use of the coil or loop for ordinary receiving purposes to replace the antenna, one of its most important practical applications comes from its directional qualities. It requires but little thought to realize that a coil placed with its winding plane perpendicular to the direction of travel of passing electromagnetic waves will have induced in it no voltage at all, while if it is turned around through 90 degrees so as to be in line with the wave propagation it will be threaded by maximum flux and develop its maximum *e.m.f.* This at once presents the possibility of locating the direction of any transmitting station that may be heard, and it has been found possible by correct design to build apparatus capable of locating such directions with an error not exceeding plus or minus ½ degree. Actually, a great many factors affect the accuracy of the device as a direction finder and the best results can only be obtained by properly taking all of them into account. Theoretical analysis of the effects involved has led to the development of methods for greatly improving the accuracy of the loop for direction finding and also to the important invention of a method for determining, by means of a single isolated loop structure, not only the *line* of a distant transmitting station but also its *sense* or *absolute* direction.

It is the purpose of the present paper to summarize an investigation that has been carried out in the U. S. Signal Corps Radio Laboratories during the latter part of 1917 and 1918 of all of these factors that enter into the efficient design of direction find-

ing apparatus using the loop antenna. No loop receiver can ever be made to be as efficient a collector of radio energy as a well-designed elevated antenna system and recourse is usually had, therefore, to the use of very sensitive detecting apparatus involving vacuum tube detectors and vacuum tube amplifiers in order to get the desired strength of signal. There are other reasons, also, of a more involved nature which make it necessary to employ specially designed amplifying apparatus in connection with the loop direction finder, so that while the main points to be discussed in this paper are those dealing with the efficiency of the loop as a receiver, its proper design, and with its directional properties, a few paragraphs are also devoted to investigations that have been made on the subject of amplification for this particular class of work. The experimental data presented with reference to the design of the loop for high efficiency is reasonably complete and would appear to be sufficient to allow fairly exact mathematical formulation. This phase of the problem has not been developed, however, in the present report.

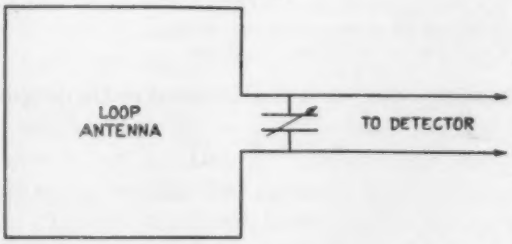
PART I.

DESIGN OF THE LOOP RECEIVER.

GENERAL THEORY.

THERE are several ways in which the loop receiver may be connected to the detecting apparatus, but the one most commonly used and the one that is considered in this paper is that

FIG. 1.



shown in Fig. 1, where it will be seen that a variable air condenser is connected directly across the loop terminals for tuning and the voltage developed across this condenser is impressed upon the detector.

The engineering problem presented is that of proportioning the loop so that this voltage will be as high as possible. The points involved, as will appear shortly, are:

1. Determination of best size of loop and number of turns for given wave-length,
2. Effect of spacing the turns of the winding,
3. Effect of size and kind of wire,
4. Effect of insulation and coloring matter in same,
5. Proper size of tuning condenser,
6. Effect of proximity of loop to walls of rooms,
7. Effect of the presence of dead or unused turns on coil;

and in order to come to practical conclusions of value to the engineer in building such coils it was necessary to study several other points, such as the effects of obtaining a given flux linkage or a given inductance through the use of large area and few turns or with smaller area and a large number of turns. Thus, in the following pages, sections are also devoted to the cases of:

1. Constant flux linkages with variable turns and area.
2. Constant inductance with variable turns and area.

This part of the investigation is then completed by working out from the data accumulated a design chart which enables all of the principal dimensions of a loop to be quickly determined when the working wave-length is given.

Let

h = Instantaneous value of field intensity at the loop.
H_o = Max. instantaneous value of h.
λ = Wave-length.
N = Number of turns on loop.
A = Area of a turn.
L = True self-inductance of loop.
R = Total effective resistance of loop.
C = Capacity of tuning condenser.

The instantaneous value of *e.m.f.* induced in the loop is

$$e = N \frac{d\phi}{dt} \cdot 10^{-8}$$
$$= NA \frac{dh}{dt} \cdot 10^{-8} \quad \ldots\ldots (1)[1]$$

If the field varies harmonically,

$$h = H_o \sin \omega t \quad \ldots\ldots (2)$$

[1] If the loop is of the flat pancake type the value of NA to use is the summation of the individual areas of all the turns, *i.e.*, $\Sigma_1^N A$.

and (1) becomes

$$e = NAH_o \omega \cos \omega t \times 10^{-8}$$

Therefore, the instantaneous current in the loop and through the tuning capacity, C, is, at resonance,

$$i = \frac{E}{R} = \frac{NAH_o \omega \cos \omega t \times 10^{-8}}{R}$$

and the effective value of this current is

$$I_{eff} = \frac{NAH_o \omega \times 10^{-8}}{R\sqrt{2}}$$

The voltage across the tuning condenser due to this current is, as has been stated above, used to actuate the detector and its value will be a measure of receiving efficiency. This voltage is (approximately)[2]

$$\begin{aligned} E_c &= I_{eff}/\omega C \\ &= \frac{NAH_o \times 10^{-8}}{\sqrt{2}RC} \\ &= \frac{4\pi^2 V^2 H_o}{\sqrt{2}} \cdot \frac{NAL}{\lambda^2 R} \times 10^{-8} \\ &= K\left(\frac{NAL}{\lambda^2 R}\right) \qquad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (3) \end{aligned}$$

From this it appears that we have in general to deal with the problem of making the factor $NAL/\lambda 2_r$ as large as possible. This factor has been termed the "reception factor" in what follows.

At first sight, it would seem that a given loop would become increasingly more effective as the wave-length was shortened. In practice, however, such is not the case and audibility measurements have indicated that there is a certain best wave-length for a given loop above and below which the reception falls off.

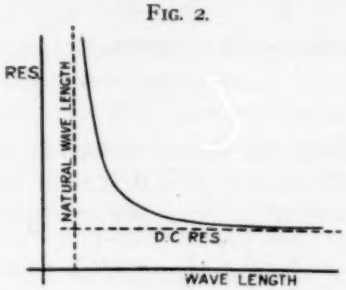
The reason for this can be directly traced to the fact that the loop resistance is not constant but changes with the wave-length. At very long wave-lengths the resistance approaches its *d.c.* value. As the wave-length is shortened, however, the resistance increases, slowly at first, up to a point 2 or 3 times the natural period of the coil when it rises almost asymtotically (see Fig. 2), and it is this inverse variation of effective resistance with wave-length

[2] This expression is not exact because part of the capacity is that of the loop itself which is distributed and does not all carry the total current I.

that produces the maximum value in the reception at a particular wave-length already mentioned. The reception factor curve drawn as function of wave-length has the form shown in Fig. 3.

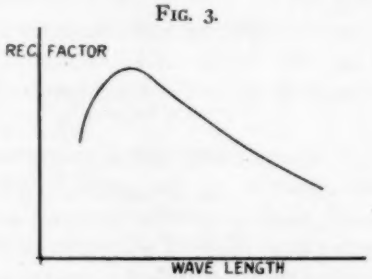
The variation of resistance just described is due to a combination of several effects, being chiefly caused by the capacity between

FIG. 2.



turns of the winding, but involving also the effects due to eddy current loss, skin effect, electromagnetic radiation, and losses in nearby imperfect dielectrics. It is very greatly affected by the number of turns, the size of the loop, and the spacing of the wires. It is also influenced, though to a lesser extent, by the actual *d.c.*

FIG. 3.



value of resistance, the diameter and shape of the wire and whether stranded or solid.

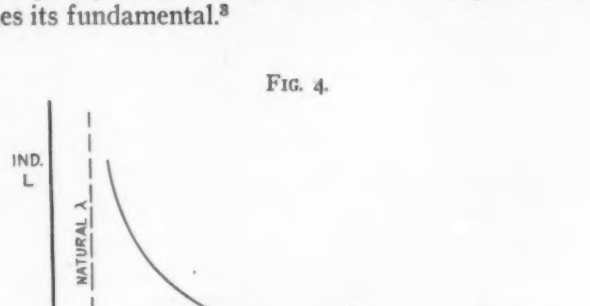
It is to be noted that the apparent inductance of the loop varies with the wave-length (Fig. 4) in a manner similar to the resistance but less abruptly. The increase in apparent inductance at short wave-lengths is due to the effective shunted capacity of the loop. The slight rise at long wave-lengths is due to the disappearance of skin effect.

For a given wave-length the equation (3) would indicate the

use of many turns, large self-induction and a large loop. These factors cannot be changed, however, without at the same time raising the natural wave-length of the loop and its effective resistance; and there actually comes a time when increasing the size of the loop and the number of turns is detrimental. There is, in fact, a certain best value of turns, area, spacing, etc., for any given wave-length. For short wave-lengths only a few turns can be used and the proper combination is quite critical, while for long waves where a large number of turns are employed, deviation from exactly best proportions is less serious.

No loop may be efficiently used at wave-lengths less than 1.5 to 2 times its fundamental.[3]

FIG. 4.



METHOD OF MEASURING LOOP EFFICIENCY.

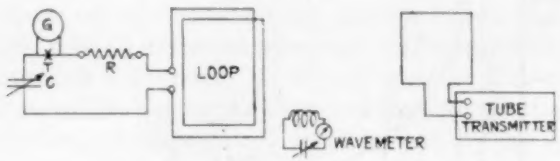
The method used in studying the various factors that enter into the design of loops was very simple. For each different set of conditions the effective resistance was measured at different wave-lengths, and from the physical dimensions of the loop and the data on its resistance thus obtained the reception factor $NAL/\lambda 2r$ was calculated. This procedure was particularly well adapted to manipulation in the laboratory, and was justified by the results of a number of special tests made over considerable distances in which the audibility of received signals was measured directly at different wave-lengths. A description of these tests

[3] The above discussion neglects entirely the reaction of the induced loop oscillation on the wave. The effect is very small, however, with this type of antenna.

is given later. They check the performance of the loop as calculated from measurements of its resistance.[4]

The "Resistance Variation Method" was used in determining loop resistance (see Fig. 5). The loop to be measured was inserted in a series circuit containing a variable air condenser known to be free from losses, and a low resistance thermoelement, *T*, and galvanometer, *G*. The galvanometer chosen was one which gave, accurately, deflections proportional to the square of the current in the thermoelement *throughout its entire range*. The thermoelements used were made up at the National Bureau of Standards and had resistances somewhat less than one ohm. The galvanometer was a single pivot Paul instrument, giving full scale deflection with about 80 milliampères. Various known resistances could be inserted at *R*. These resistances consisted

FIG. 5.



of fine manganin wires a centimeter or so in length enclosed in glass tubing and fixed to heavy copper wire terminals which dipped into small mercury cups.

The loop to be measured was coupled directly with and carefully turned to a vacuum tube generating circuit, the wave-length measured; and several resistances inserted successively at *R*, the galvanometer deflection being read for each resistance. The resistance of the loop was then calculated from the formula

[4] Attention should be called to the fact that the value of resistance in the expression for the reception factor is the total effective resistance of the oscillatory circuit which limits the flow of current therein, and this comprises not only the resistance of the loop alone, but also the resistance of the tuning condenser and an effective resistance introduced into the circuit by the attached detector. If a well designed air condenser is used for tuning, the resistance of this element can be neglected. The resistance introduced by the attached detector when this is a vacuum tube is also very small and need not be considered in any but exceptional cases. It can be calculated or determined experimentally by the methods given in Appendix A.

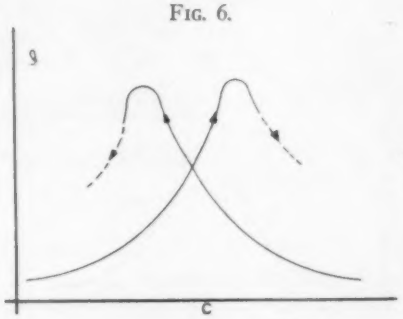
$$R = \frac{R_2 - R_1 \sqrt{\frac{\delta_1}{\delta_2}}}{\sqrt{\frac{\delta_1}{\delta_2}} - 1} - R_7$$

R_1 and R_2 = different values of inserted resistance.
δ_1 and δ_2 = galvanometer deflections corresponding to R_1 and R_2.
R_7 = resistance of thermoelement.

The average of several values determined in this way for any given set of conditions gives all the accuracy desired.

Precautions to be Observed.—In making measurements of this kind it is necessary to arrange the set-up in a large room or out-of-doors and well away from possible absorbing resonators.

FIG. 6.



Proximity of the loop to the walls of a room may result in high effective resistance due to dielectric losses in same. The effect may be considerable, as is shown by one of the tests, when the loop is one of large size and many turns so that there is considerable condenser effect to the walls of the room.

Very loose coupling should be used between the generating and measuring circuits. This point must be carefully watched, for two reasons. First, when the coupling is tight the voltage induced in the loop will change with different inserted resistances.[5] In the second place, there will be two coupling waves, either of which may be tuned to and the results will be inaccurate, due to the impurity of the tuning. Fig. 6 shows the nature of this effect. The coupling should always be made loose enough so that only one hump is present, as in Fig. 7. When the adjustments

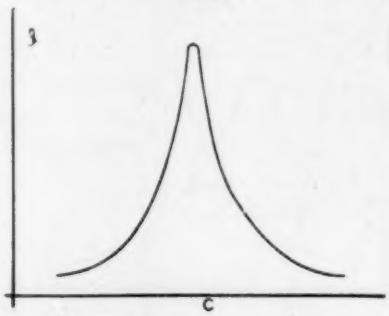
[5] Due to reaction on the exciting circuit.

are properly made an ammeter in the generating circuit will drop only very slightly at resonance. When the coupling is too tight, the reading falls abruptly when the test circuit is brought in tune. The coupling must not be changed during one series of observations on a given wave-length.

The resistance of the thermoelement should be checked occasionally to see that it does not change.

The leads of the loop should be as short as possible, especially for the smaller loops, for in such cases the capacity of the leads may be a large part of the total coil capacity and the resistance will be seriously affected.[6]

FIG. 7.



RESULTS OF LOOP RESISTANCE MEASUREMENTS.

The results of the present experiments are here recorded graphically and in general in two parts.

[6] It might be supposed that the above method would not give entirely accurate results, especially at the shorter wave-lengths, due to the fact that in such cases the current distribution varies through the circuit and is greater near the centre of the loop than at the ends. To test this point a number of resistance measurements were made by another method for verification. In this method the various known resistances were inserted in the circuit to be measured at its electrical centre and the galvanometer with its thermoelement was connected to an auxiliary coil coupled inductively with the loop. With this arrangement the deflections of the galvanometer are practically independent of the current distribution in the loop. When all the proper precautions had been taken it was found that the results obtained by this method checked those obtained by the method described in the text practically exactly.

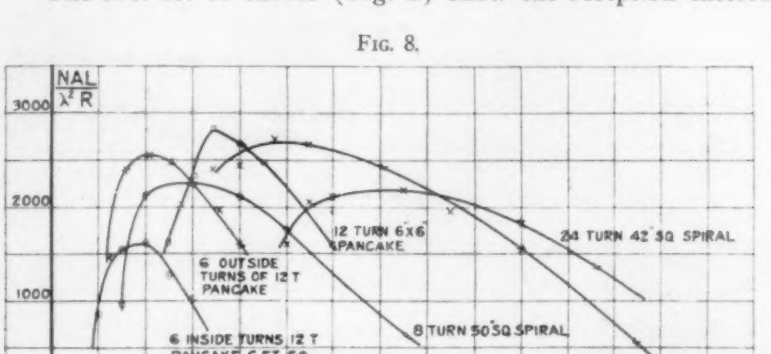
1. The resistance of the loop as function of wave-length.
2. The reception factor as function of wave-length.

The true inductance was estimated from the curve of apparent inductance.

I.

The first set of curves (Fig. 8) show the reception factors

FIG. 8.


NAL/λ²R
3000
2000
1000
12 TURN 6X6 PANCAKE
24 TURN 42" SQ SPIRAL
6 OUTSIDE TURNS OF 12 T PANCAKE
6 INSIDE TURNS 12 T PANCAKE 6 FT SQ
8 TURN 50" SQ SPIRAL
15 TURN PANCAKE 70" SQ
200 400 600 800 1000 12 14 16 18 2000 22 24 26 28 3000
WAVE-LENGTH

of a miscellaneous lot of loops taken at random from loops that had been in use on direction finding experiments. It is interesting to compare these curves with those of some of the later loops in which the best proportions of spacing, diameter, number of turns, etc., were realized. These early loops were relatively inefficient.

The following data are descriptive of this lot of loops:

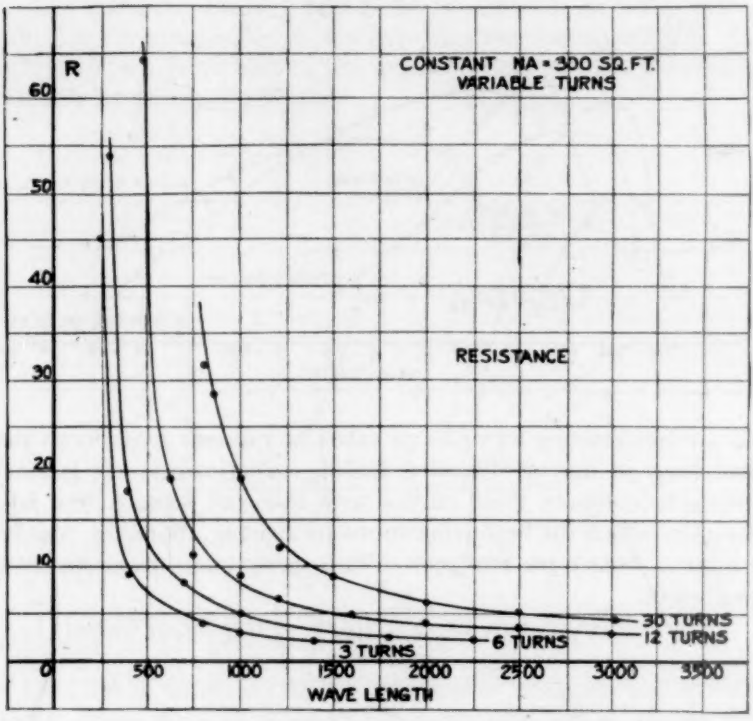
Loop	L cms.	Description
1	580,000	2 crossed loops at right angles 6 ft. sq. 2" spacing No. 16 lampcord.
2	70,000	4 turns bronze antenna wire on 50" sq., solenoid spacing ½ "
3	230,000	8 turns same as No. 2.
4	94,000	Inside 6 turns of 12 turn pancake 6 ft. sq., spacing 1¾" stranded No. 18.
5	155,000	Outside 6 of same.
6	340,000	All 12 turns of same.
7	800,000	15 turn pancake 70"×70" outside spaced $\frac{3}{16}$" No. 20 wire.
8	2,100,000	24 turn 42" sq. solenoid closely wound litz. 32 No. 38 enameled wires.

II.

CONSTANT FLUX LINKAGES.

As has been shown, the *e.m.f.* induced in a loop depends, among other things, upon the total flux linkages; that is, upon the

FIG. 9.

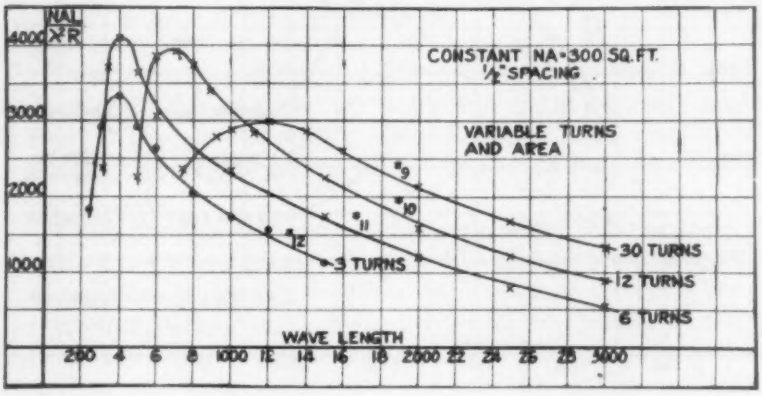


value of the product NA. Now it is not immaterial how a given value of this product be obtained. Either a large loop of few turns or a smaller loop of more turns may be used, but the characteristics of the two loops are widely different.

This is well shown by the curves of Figs. 9 and 10, which give the resistance and reception factor for 4 different loops whose size and number of turns were varied in such a way as to keep the product NA constant.

It will be seen from Fig. 10 that for short wave-lengths it is better to use large loads of a few turns, while for long waves smaller loops having more turns are preferable. This general conclusion is important and should never be lost sight of, although, as will be seen later, there finally comes a time at very long wave-

FIG. 10.



lengths when it is again better to decrease the turns and increase the size.

The 4 loops just mentioned have the following constants:

Loop	Turns	Area, sq. ft.	Spacing	Type	L cms.
9	30	10	½"	Solenoidal	1,250,000
10	12	25	½"	Solenoidal	582,000
11	6	50	½"	Solenoidal	280,000
12	3	100	½"	Solenoidal	120,000

III.

CONSTANT INDUCTANCE.

In proportioning a receiver for given wave-length, it is always best to use small tuning condensers, because this offers the possibility of large loop inductance (turns and area). A given inductance may be obtained either by few turns on a large frame or many turns on a small frame. There is a difference, however, as regards the relative effectiveness in the two cases.

Figs. 11 and 12 show the results of a comparison of several

FIG. 11.

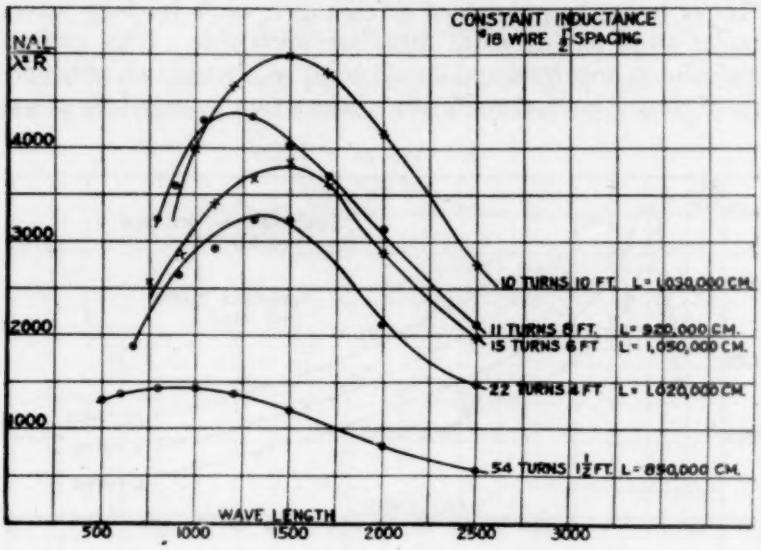
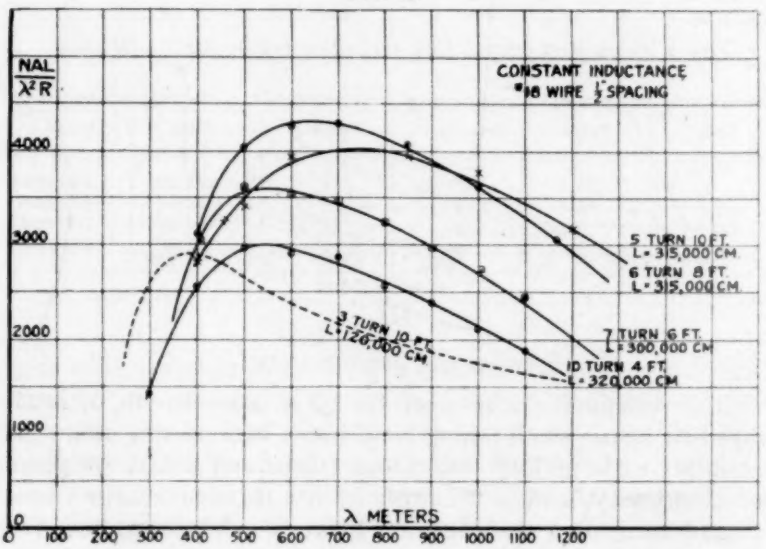

CONSTANT INDUCTANCE
#18 WIRE 1/2" SPACING
NAL/λ²R
4000
3000
2000
1000
10 TURNS 10 FT. L = 1,030,000 CM.
11 TURNS 8 FT. L = 920,000 CM.
15 TURNS 6 FT. L = 1,050,000 CM.
22 TURNS 4 FT. L = 1,020,000 CM.
54 TURNS 1½ FT. L = 890,000 CM.
WAVE LENGTH
500
1000
1500
2000
2500
3000

FIG. 12.


CONSTANT INDUCTANCE
#18 WIRE 1/2" SPACING
NAL/λ²R
4000
3000
2000
1000
0
5 TURN 10 FT.
L = 315,000 CM.
6 TURN 8 FT.
L = 315,000 CM.
3 TURN 10 FT.
L = 126,000 CM.
7 TURN 6 FT.
L = 300,000 CM.
10 TURN 4 FT.
L = 320,000 CM.
λ METERS
0
100
200
300
400
500
600
700
800
900
1000
1100
1200

coils in which the number of turns and the area of the loops were varied, but in such a way as to maintain the inductance approximately constant. It will be seen that in this case the maximum reception factor always occurs at approximately the same wave-length, regardless of whether the given inductance is obtained by few turns and large area or the reverse. The curves become flatter as the number of turns increases, which means that a coil of many turns responds efficiently over a wider range of wave-lengths than does one of a few turns.

This last statement has direct application to small tuning coils as well; for example, the secondary of the ordinary loose-coupler. The general theory outlined above holds exactly for this case, and the same type of characteristics may be obtained for such coils.

While the data of this test does not cover very large loops of only one or two turns and so cannot be interpreted for such extreme cases, it does show that within the range used it is better for given inductance to use large loops with few turns. It would appear that for given inductance a single turn very large loop would be best, as the total flux (NA) would then be maximum.

IV.

DETERMINATION OF BEST SPACING.

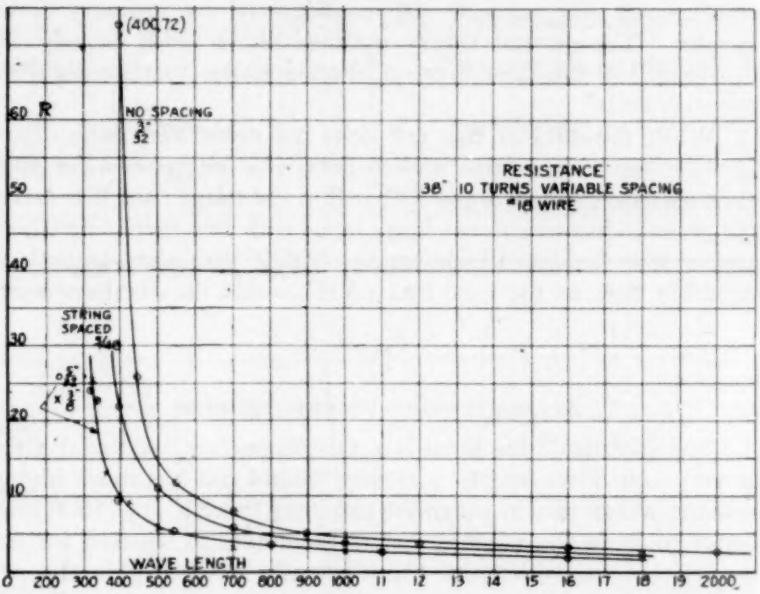
The spacing of the turns is a most important factor. Except at very long wave-lengths a closely wound coil has much higher resistance than one on which the turns are spaced. It is, therefore, better to space the winding unless the coil is to be used for extremely long wave-lengths. It is actually better in this case not to separate the wires very much because of the sacrifice in inductance.

For a given size of loop and given number of turns, *i.e.*, constant flux linkages, we have two opposing effects resulting from an increase in spacing, the decrease in self-inductance *vs.* the decrease in resistance. At first, the resistance decreases more rapidly than the inductance, so that increasing the spacing is for a time advantageous. A point is soon reached, however, where further increase in spacing affects the resistance very little, and this point should not be exceeded; for the inductance still falls off and the reception factor is therefore lowered.

If the inductance is kept constant by adding turns as the spacing increases, the best value of spacing is, of course, not so sharply defined, but still exists and corresponds to the point where the resistance ceases to be appreciably affected. It coincides very closely with the best value as determined for constant turns.

The nature of the several effects just mentioned is shown in Figs. 13, 14, 15, 16, 17, 18, 19, 20. Figs. 13, 15, 17, 19 show the resistance as function of wave-length for various sizes of coils

FIG. 13.



(3, 6, 10, 15 ft.) wound with 10 turns of No. 18 wire and spacing systematically varied. Figs. 14, 16, 18, 20 show the corresponding reception factor curves. A best value of spacing is clearly evidenced in each case. Figs. 13-A and 15-A are given to show the effect of spacing on inductance and should be studied in conjunction with the resistance curves for the same loops (Figs. 13 and 15).

It will be noticed that in general the closer the spacing the greater is the useful range of wave-lengths of the loop. Wide spacings make the reception factor curve peaked. It is, therefore,

FIG. 13A.

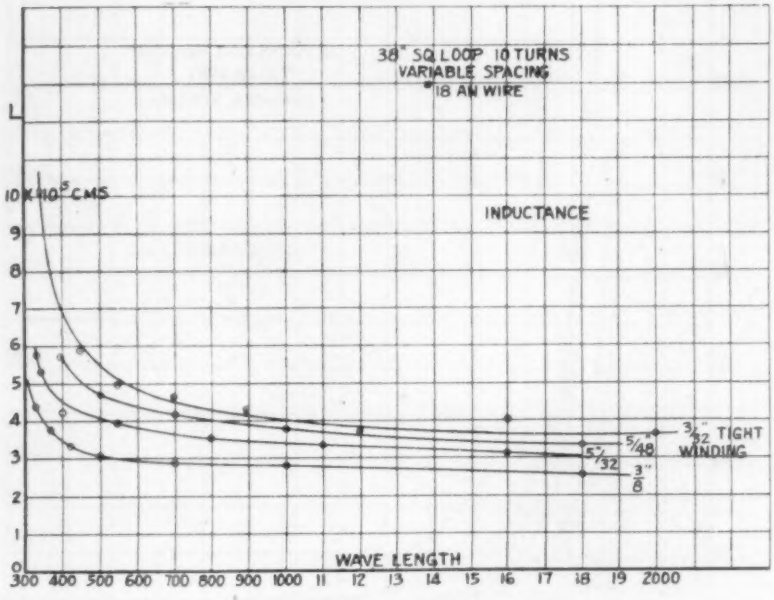


FIG. 14.

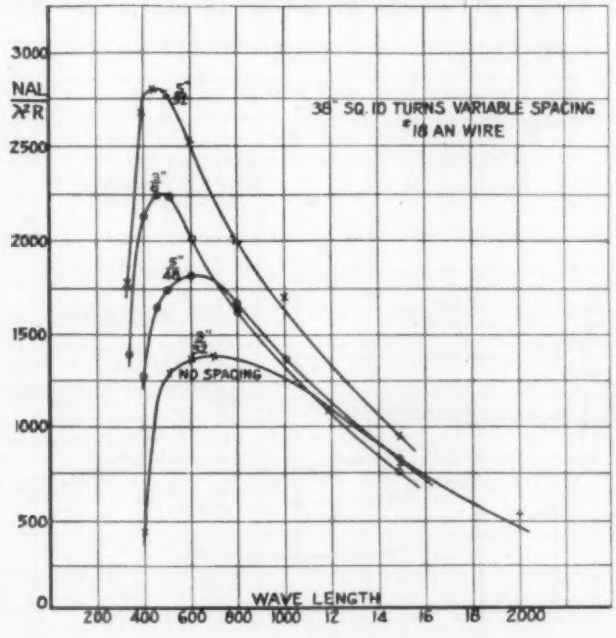


FIG. 15.

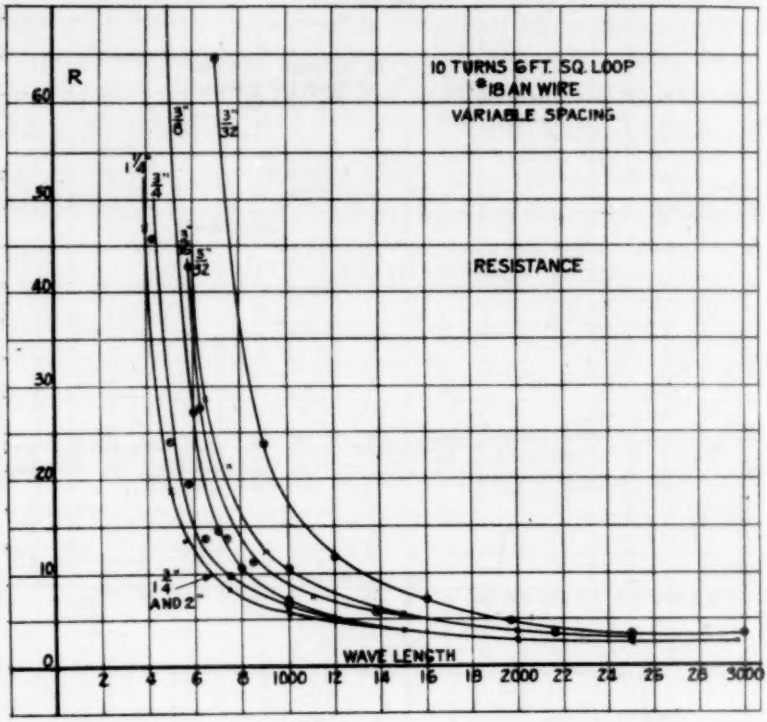


FIG. 15A.

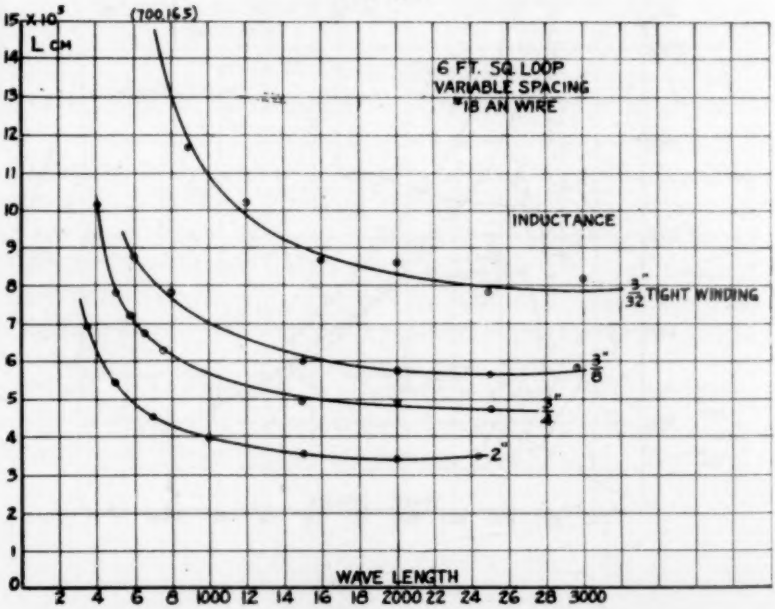


FIG. 16.

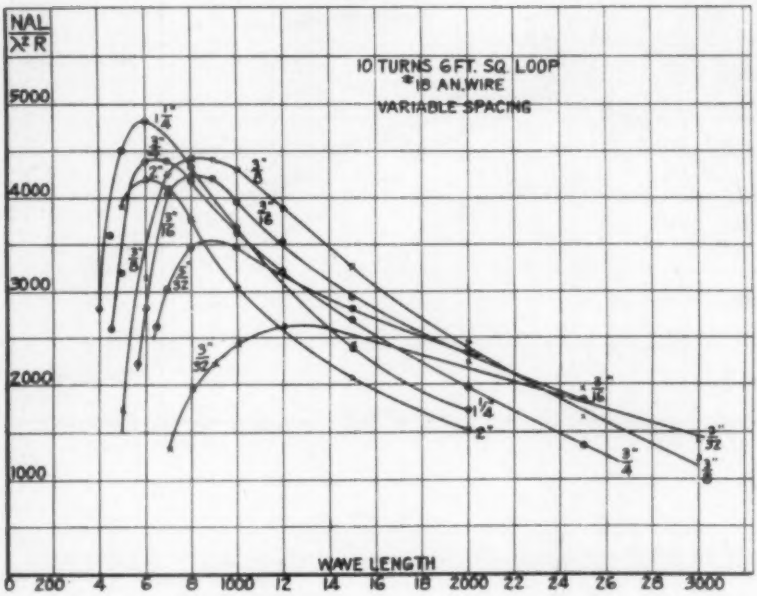

NAL/λ²R
10 TURNS 6 FT. SQ. LOOP
#18 AN. WIRE
VARIABLE SPACING
5000
4000
3000
2000
1000
WAVE LENGTH
0 200 4 6 8 1000 12 14 16 18 2000 22 24 26 28 3000

FIG. 17.

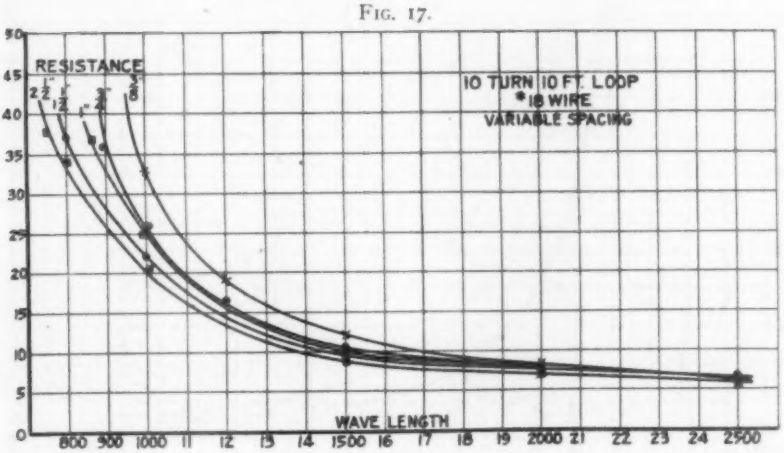

RESISTANCE
10 TURN 10 FT. LOOP
#18 WIRE
VARIABLE SPACING
50
45
40
35
30
25
20
15
10
5
0
WAVE LENGTH
800 900 1000 11 12 13 14 1500 16 17 18 19 2000 21 22 23 24 2500

FIG. 18.

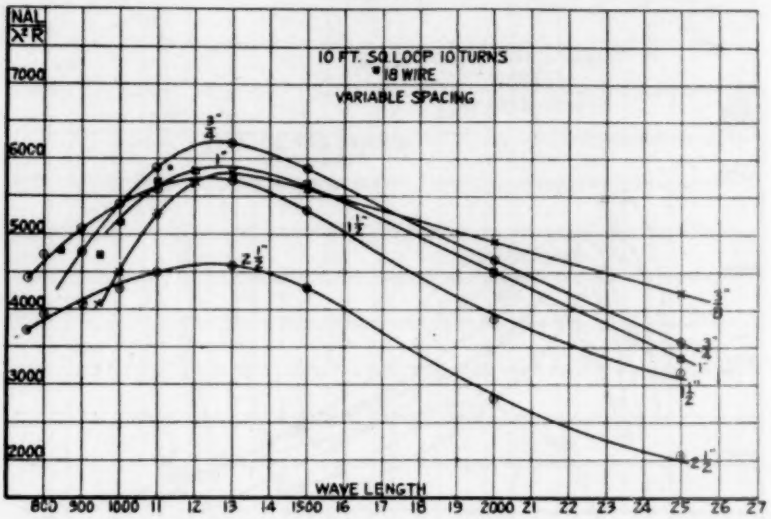

NAI/X²R
10 FT. SQ. LOOP 10 TURNS
#18 WIRE
VARIABLE SPACING
7000
6000
5000
4000
3000
2000
WAVE LENGTH
800 900 1000 11 12 13 14 1500 16 17 18 19 2000 21 22 23 24 25 26 27

FIG. 19.

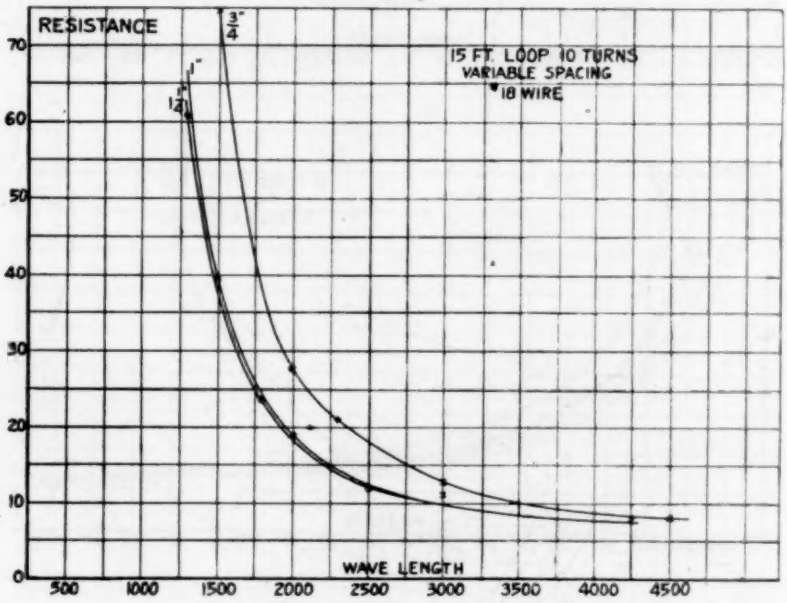

RESISTANCE
15 FT. LOOP 10 TURNS
VARIABLE SPACING
#18 WIRE
70
60
50
40
30
20
10
0
WAVE LENGTH
500 1000 1500 2000 2500 3000 3500 4000 4500

FIG. 20.

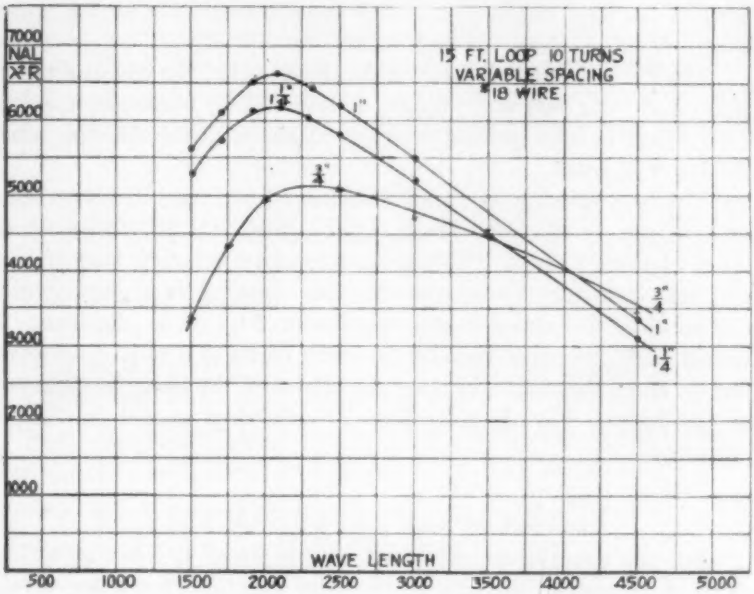
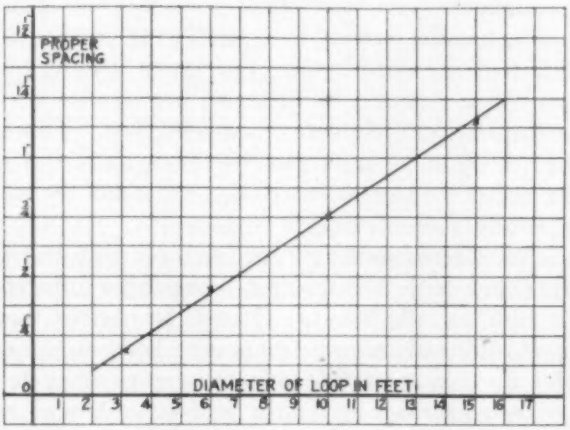

15 FT. LOOP 10 TURNS
VARIABLE SPACING
#18 WIRE
7000
NAL
XER
6000
5000
4000
3000
2000
1000
WAVE LENGTH
500
1000
1500
2000
2500
3000
3500
4000
4500
5000

FIG. 21.


PROPER
SPACING
DIAMETER OF LOOP IN FEET
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17

necessary to choose the best spacing not simply as that which gives the highest maximum in the reception factor curve but the sharpness of this curve should also be considered. The effectiveness of the loop ought not to fall away too quickly as the wave-length changes from the best value.

The curves show that the natural period of the coil and correspondingly the best wave-length is lowered by increased spacing. This effect is most pronounced for changes in the spacing when the latter is small.

The best spacing has been determined for four different sizes of loop, *viz.*, 3 ft., 6 ft., 10 ft., 15 ft. (Figs. 14, 16, 18, 20), and there appears to be a direct proportionality between size of loop and best spacing. Thus, when the best spacing is plotted against size of loop the straight line relation of Fig. 21 is obtained. It would seem that the capacity between turns is a most important factor, since this also increases directly with the linear dimensions of the loop. The data of Fig. 21 are very useful in designing loops.

V.

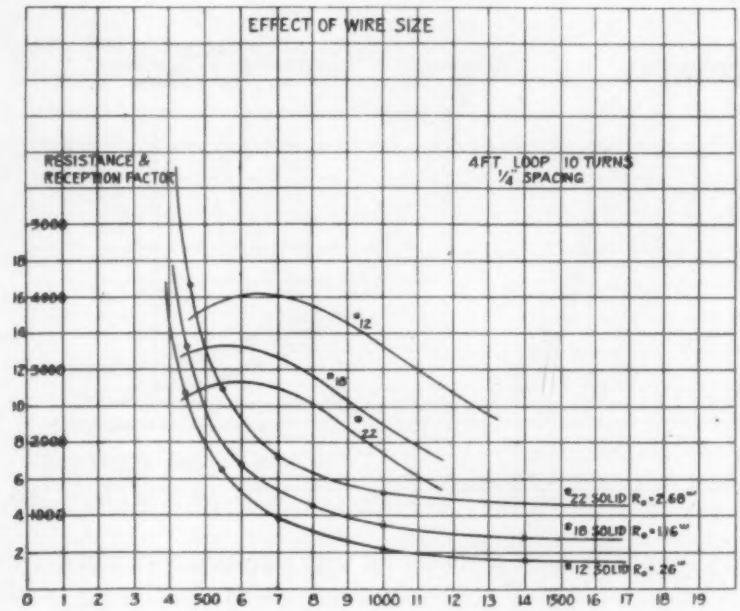
EFFECT OF SIZE AND KIND OF WIRE.

For the wires ordinarily used, that is, from say No. 22 to No. 14 B. & S. gauge, the size of the wire has little influence on the best spacing as determined above. In general, large wires should be spaced farther apart than small ones, but this effect is only pronounced when the spacing is so small as to be comparable with the diameter of the wire itself. For given spacing under these conditions it may actually be better to use smaller wire so as to make the ratio of wire diameter to spacing less. This is particularly true for short or moderate wave-lengths. For very long waves the resistance approaches its *d.c.* value and the smaller wire in that case offers no advantage.

Fig. 22 gives the resistance curves for three 10 turn coils wound on a 4 ft. frame with ¼″ spacing, using three different sizes of wire, No. 22, No. 18, No. 12. It will be noticed that at short wave-lengths the resistance depends very little on the size of the wire, while for longer wave-lengths the curves separate more and more and are controlled by the *d.c.* resistance in each case. This figure also shows the reception factor curves for the three coils just mentioned, and it is seen that the best wave-length for a given coil is independent of the size of wire with which it is wound.

There is some advantage, of course, in the matter of efficiency if the size of wire is greatly increased. This is not so great as might be at first imagined, however; for in the first place, the effect of *d.c.* resistance on the total effective resistance in the neighborhood of best working wave-length is of rather secondary order, and in the second place, the inductance of the large wire coil is less than that of a coil using fine wire so that the reception

FIG. 22.



factor $NAL/\lambda 2_r$ is prevented from increasing as rapidly as would be indicated by variation in resistance alone.

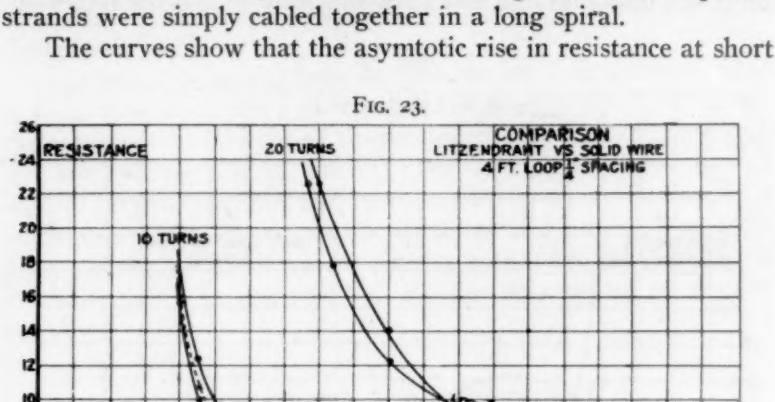
Litzendraht.—In order to compare the relative efficiency of solid wire with that of litzendraht and stranded wire the curves of Fig. 23 were taken. Two different size coils were compared, one of 10 turns and one of 20 turns. Both were on frames 4 ft. square and the spacing was $\frac{1}{4}''$. For the 20 turn loop No. 18 solid wire was compared with litzendraht having about 45 per cent. of the equivalent cross-section and composed of three bundles of sixteen No. 38 enameled wires each. The separate strands

were woven criss-cross, in and out, in such a way as to form a sort of tubular conductor.

For the 10 turn loop the same wire was compared with the No. 18 solid, and in addition a stranded conductor having approximately the same cross-section as the No. 18 was also used. This latter consisted of three bundles of twenty-seven No. 38 silk-covered strands each; but instead of being woven the separate strands were simply cabled together in a long spiral.

The curves show that the asymtotic rise in resistance at short

FIG. 23.



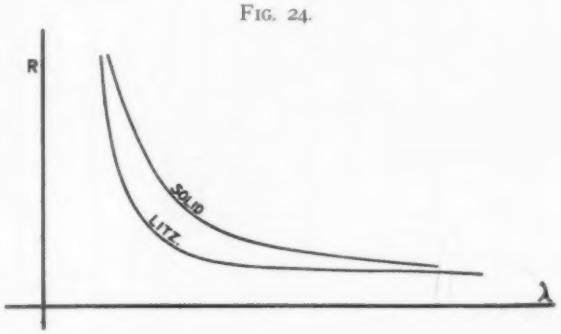
wave-lengths is much more abrupt with stranded wire and litzendraht than with solid wire. At short waves there is very little advantage in the use of litzendraht over solid wire for a given total cross-section; and the same is true for very long waves, because the resistance for both wires is approaching the same *d.c.* value. But for intermediate wave-lengths the stranded wire or litzendraht is better. Fig. 24 shows the nature of the effect on an exaggerated scale.

If the litzendraht has less cross-section than the solid wire, then the two curves will cross (see Fig. 23) and we then have the interesting conclusion that for wave-lengths above a certain value the solid wire has less resistance than the litzendraht and is therefore better, while below this wave-length the litzendraht

should be used. Or it may result that the two curves practically coincide for a portion of their length and thus the use of litzendraht or solid wire is immaterial.

Effect of Insulation Covering.—When the wires are wound tightly together there are losses in the dielectric between turns, that is, in the insulation, which raises the effective resistance of the coil. When the wires are spaced several diameters, however, it is immaterial whether they be insulated or bare. Thus, the resistance curve of a 10 turn coil of No. 18 bare wire spaced ¼″ on a 4 ft. frame was compared with those of similar coils of No. 18 d.c.c. white and No. 18 d.c.c. paraffined blue wires. The three curves coincided perfectly.

FIG. 24.



The reason for comparing the blue insulated wire was that an analysis of the insulation showed the coloring matter to contain iron salt (ferro-ferri-cyanide) which it was thought might be magnetic and therefore affect the overall resistance. It must be concluded that coloring matter has little or no effect on the resistance, at least for the spacings used.

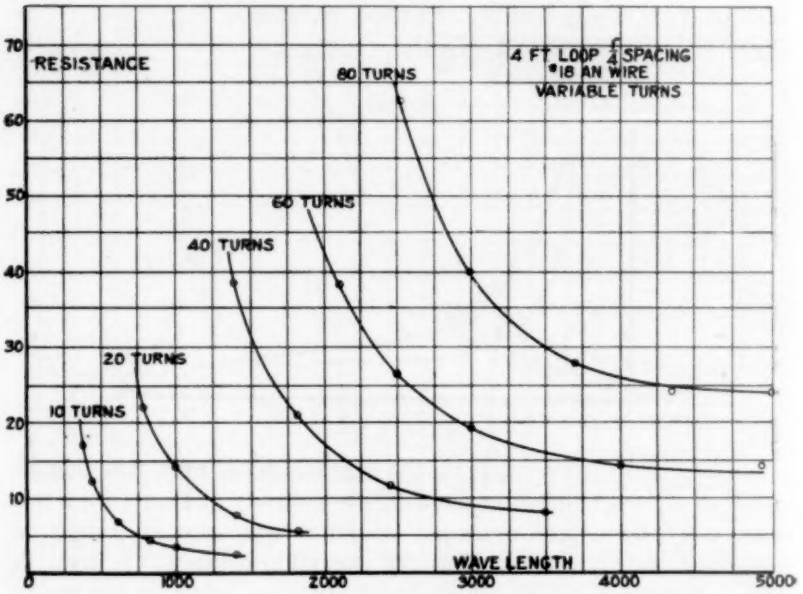
VI.

DETERMINATION OF BEST SIZE OF LOOP AND NUMBER OF TURNS FOR GIVEN WAVE-LENGTH DESIGN CHART.

The results of Sections 2 and 3 above show that for given inductance it is best to use for N the minimum and for A the maximum, while for given flux linkages the best values of N and A depend on the wave-length. Combining these conclusions we

can see that there are certain best proportionings of flux linkages and inductance. The problem is somewhat as follows: Given a certain wave-length, a small value of tuning capacity may be assumed and the required inductance calculated. This may be obtained by the use of a few turns on a large frame or many turns on a small frame. Now, at first sight it would seem as though the combination using few turns and large diameter would be best because this gives highest flux linkages [7] (Sect. 3). But, as

FIG. 25.



shown in Sect. 2, such disposition lowers the natural wave-length of the coil and hence the best working wave-length. For given wave-length, therefore, there are certain proportions of inductance and total area NA which give best results.

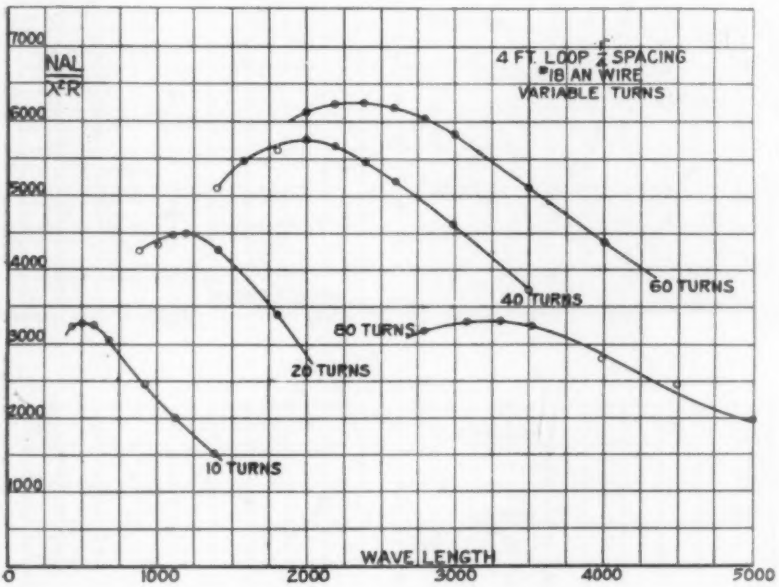
In order to work out these relations, resistance curves were taken and reception factor curves calculated therefrom for different sizes of loops and different numbers of turns. The spacing

[7] L varies as square of turns but only directly as the area. Flux linkages are proportional to NA. Hence for constant L large area and few turns give larger flux linkages than many turns and small area.

in each case was that best value, as read from Fig. 21 of Sect. 4, corresponding to the size of the loop used. The wire was No. 18 d.c.c. annunciator (solid).

Figs. 25 and 26 refer to 4 ft. loops, ¼″ spacing with turns varied from 10 to 80; Figs. 27 and 28 to 6 ft. loops $^{7}/_{16}$″ spacing; Figs. 29 and 30 to 10 ft. loops ¾″ spacing; and Figs. 31 and 32

FIG. 26.



to 15 ft. loops with 1⅛″ spacing. For this series the 4 ft., 6 ft., and 10 ft. loops were mounted horizontally in a large room, so that the edges of the loop were as far from the walls as possible. The minimum clearance in the case of the 10 ft. loop was 6 ft. The 15 ft. loop was built out-of-doors and the lower edge was 5 ft. from the earth.

Two important facts are shown by these curves. The first is that as the number of turns is increased the maximum in the reception factor curves becomes less sharply defined and the loop receives efficiently over a comparatively greater wave-length range. The second important feature is that as the number of turns on a given frame is continuously increased the maximum

FIG. 27.

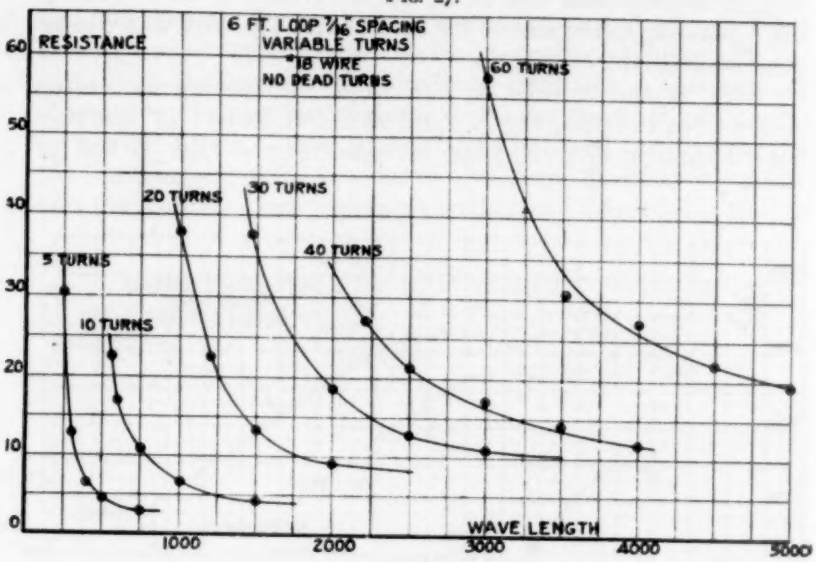

RESISTANCE
6 FT. LOOP 7/16 SPACING
VARIABLE TURNS
#18 WIRE
NO DEAD TURNS
60 TURNS
30 TURNS
20 TURNS
40 TURNS
5 TURNS
10 TURNS
60
50
40
30
20
10
0
1000
2000
3000
4000
5000
WAVE LENGTH

FIG. 28.

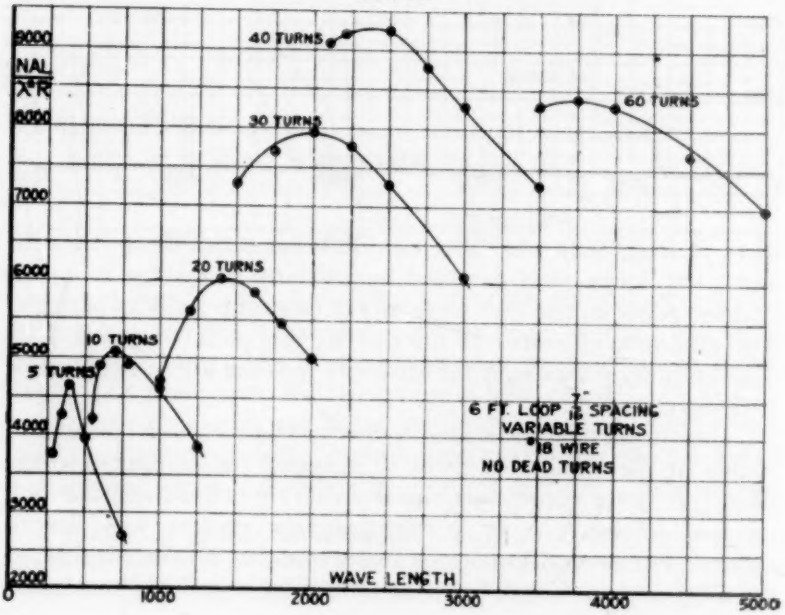

9000
NAI
λ²R
8000
7000
6000
5000
4000
3000
2000
40 TURNS
30 TURNS
60 TURNS
20 TURNS
10 TURNS
5 TURNS
6 FT. LOOP 7/16 SPACING
VARIABLE TURNS
#18 WIRE
NO DEAD TURNS
0
1000
2000
3000
4000
5000
WAVE LENGTH

FIG. 29.

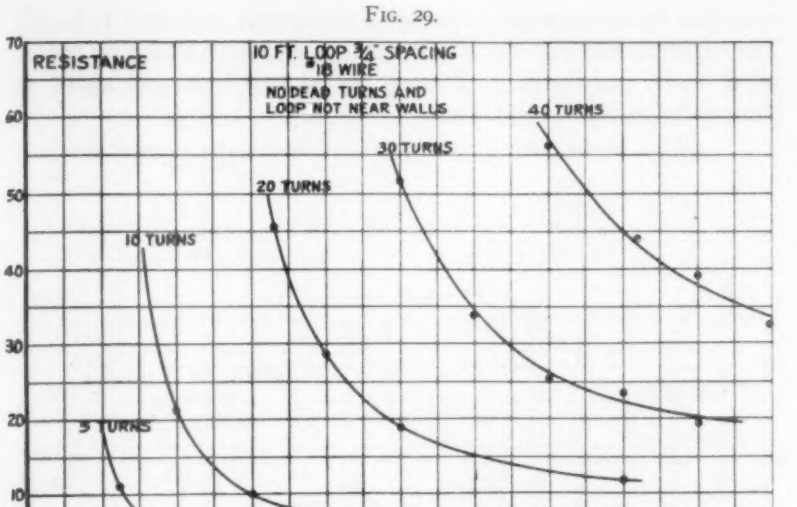
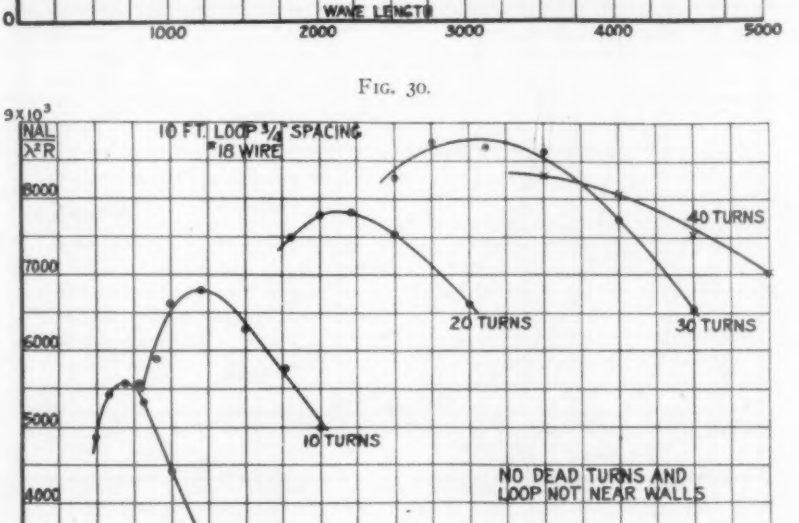

RESISTANCE
10 FT. LOOP 3/4" SPACING
#18 WIRE
NO DEAD TURNS AND
LOOP NOT NEAR WALLS
40 TURNS
30 TURNS
20 TURNS
10 TURNS
5 TURNS
WAVE LENGTH
70
60
50
40
30
20
10
0
1000
2000
3000
4000
5000

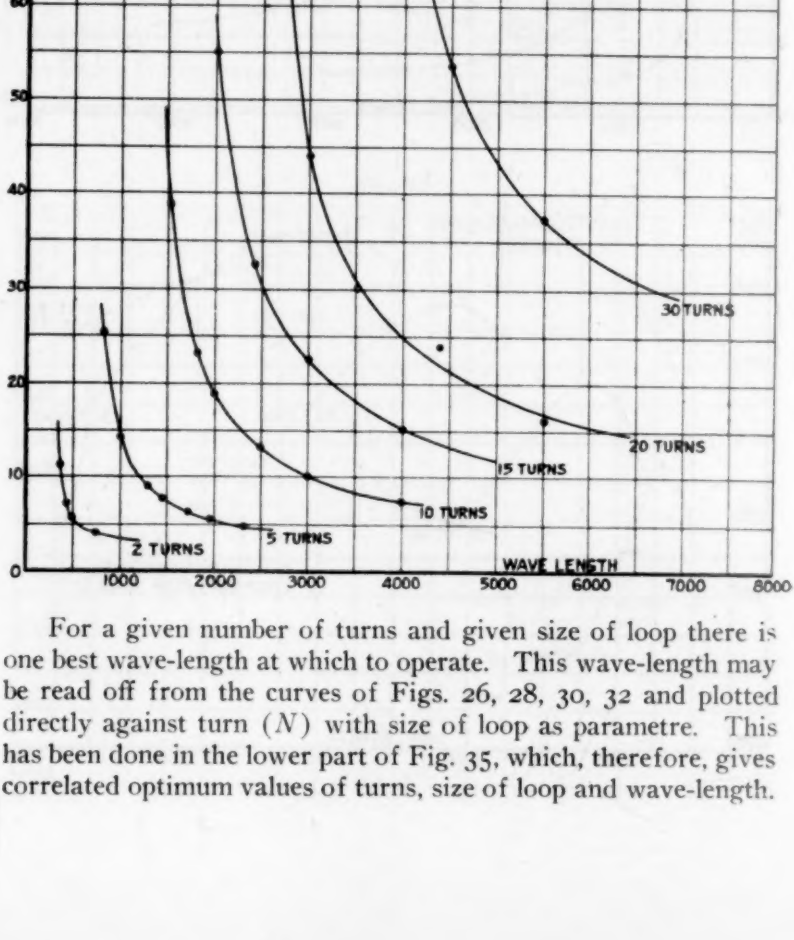
FIG. 30.


9X10³
NAL
λ²R
10 FT. LOOP 3/4" SPACING
#18 WIRE
40 TURNS
30 TURNS
20 TURNS
10 TURNS
5 TURNS
NO DEAD TURNS AND
LOOP NOT NEAR WALLS
WAVE LENGTH
8000
7000
6000
5000
4000
3000
2000
0
1000
2000
3000
4000
5000

reception factor increases, reaches a maximum, and then falls off. The highest efficiency for a 4 ft. loop occurs with about 50 turns, while for 6 ft., 10 ft., and 15 ft. loops it is less, and about as shown in the following table.

Size of loop	No. turns for best possible reception
4 feet	52
6 feet	45
10 feet	30
15 feet	25

FIG. 31.

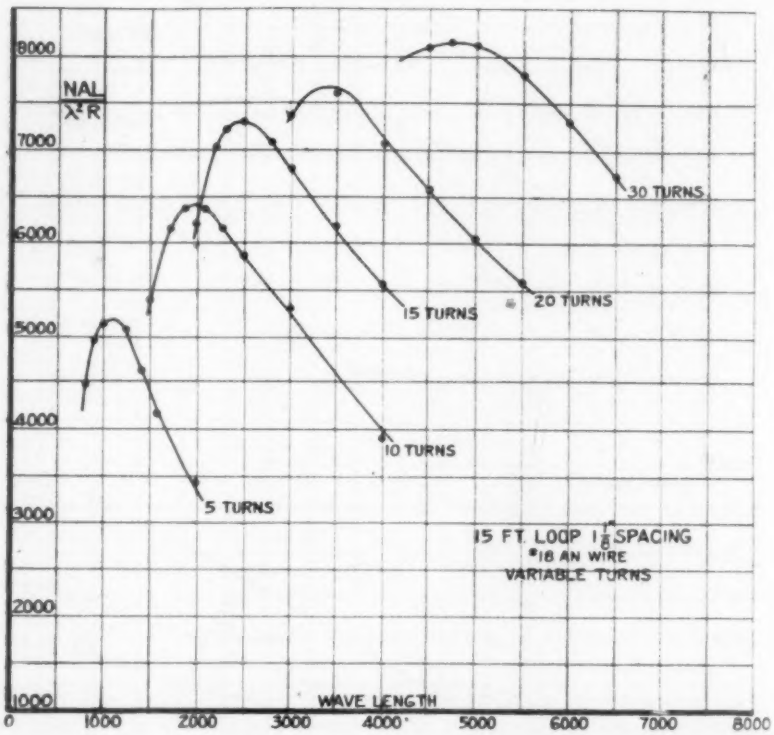


For a given number of turns and given size of loop there is one best wave-length at which to operate. This wave-length may be read off from the curves of Figs. 26, 28, 30, 32 and plotted directly against turn (N) with size of loop as parametre. This has been done in the lower part of Fig. 35, which, therefore, gives correlated optimum values of turns, size of loop and wave-length.

The 8 ft. and 12 ft. curves were interpolated by plotting values of λ against size of loop through several different ordinates of N.

The upper curves of Fig. 33 were also obtained from Figs. 26, 28, 30 and 32 by plotting the maximum reception factors indicated therein against the corresponding number of turns.

FIG. 32.



The spacing curve of this figure was drawn from the data of Fig. 21, and thus Fig. 33 becomes a complete working chart which may be used for designing loops of maximum efficiency at any chosen wave-length.

Data of a similar nature to the above, but referring particularly to short wave-lengths (200 metres to 1000 metres), have been taken, but is omitted here because of lack of space.

EXAMPLES OF THE USE OF DESIGN CHART.

As an example of the use of the design chart, let it be required to determine the elements of a loop for receiving a wave-length

FIG. 33.

of 1500 metres. The chart shows the following possible combinations:

Size of loop	No. of turns	Spacing
15 feet	7	$1\frac{1}{8}$"
10 feet	13	$\frac{3}{4}$"
6 feet	22	$\frac{7}{16}$"
4 feet	27	$\frac{1}{4}$"

In order to determine which of these is the best, reference is made to the upper reception factor curves. This gives the following data:

Size of loop	Reception factor
15 feet	5700
10 feet	7300
6 feet	7000
4 feet	5000

The 10 ft. 13 turn loop is the best, although a somewhat smaller loop down to 6 ft. may be used without serious disadvantage.

As a second example, let the required working wave-length be 3000 metres. The following set of values will be found:

Size of loop	No. of turns	Spacing	Reception factor
15 feet	17	$1\frac{1}{8}$"	7500
10 feet	30	$\frac{3}{4}$"	8800
6 feet	50	$\frac{7}{16}$"	9300
4 feet	78	$\frac{1}{4}$"	4000

It thus appears that in this case a 6 ft. 50 turn loop is best.

SIZE OF TUNING CONDENSER.

To complete the design of the receiving system it is necessary to know the size of tuning condenser needed for the loop and wave-length in question. This information can be had directly when the apparent inductance of the given loop is known at different wave-lengths. Data of this sort has been taken for all of the loops described above, though lack of space prevents its inclusion in this paper. The important result obtained from the data is that any loop can be worked at its best wave-length by the use of a variable condenser having a maximum capacity not exceeding 0.001 mf.

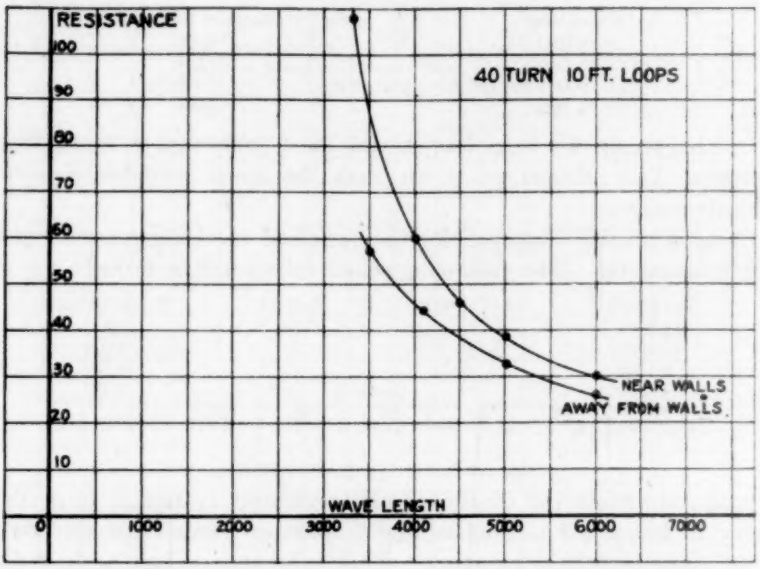
EFFECT OF DEVIATION FROM BEST WAVE-LENGTH.

If, as is often the case, a loop is to be used at several wave-lengths rather than at one fixed value, then the design chart (Fig. 33) does not tell the whole story. In this case reference should also be made to Figs. 26, 28, 30, 32 in order to choose a loop which gives the best *average* efficiency over the desired range of wave-lengths.

EFFECT OF PROXIMITY TO WALLS OF ROOM.

When a loop is used indoors, proximity to the walls or ceiling and floor of the room may cause the appearance of higher effective resistance than otherwise. The magnitude of this effect is shown in Fig. 34. Curve *A* gives the resistance of a 40 turn

FIG. 34.



10 ft. square loop with ¾″ spacing when placed vertically in a second-floor room, the upper and lower edges being 6″ from ceiling and floor, respectively. The ceiling was plaster, the floor concrete. Curve *B* is for the same loop placed horizontally in the centre of the room with a minimum distance of about 5 ft. from walls, ceiling and floor. The resistance is considerably lower in the latter case.

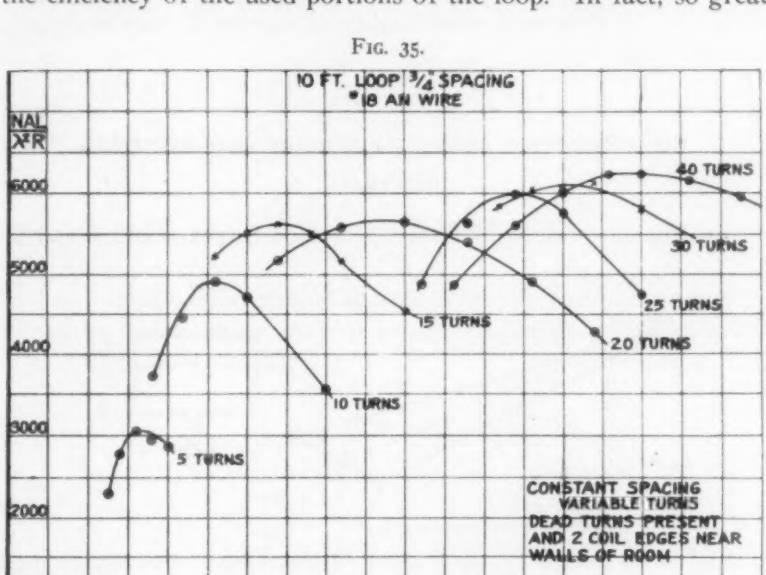
EFFECT OF DEAD TURNS.

The effect of leaving overhanging dead turns on the loop is shown in Fig. 35, which shows the reception factor as function of wave-length. The neighboring imperfect dielectric effect described in a previous paragraph is also present here, as the loop was used vertically with lower and upper edges near floor and

ceiling. The dead turns were broken into sections of 10 turns each, except for the measurement of 5 turns when there was an adjacent 5 turn section.

The exact nature and magnitude of the dead-end effect is much more vividly presented by superposing Fig. 35 on Fig. 30. It may be seen that in general the dead turns materially reduce the efficiency of the used portions of the loop. In fact, so great

FIG. 35.



is this effect on short wave-lengths that the best wave-length is actually much longer (shifted to the right) when there are dead turns present.

GENERAL REMARKS.

The working curves of the last section apply accurately only to loops wound with No. 18 solid wire. However, if wire of different size is used the interrelation of best wave-length, turns, spacing, and size of loop is not appreciably changed, but only the efficiency varies, and it is either decreased or increased for all wave-lengths. This was definitely shown by the data of Sect. 5.

All the reception factor curves are based on sustained wave reception and a detector response proportional to the *effective* undamped voltage across the loop condenser. If damped waves are being received the efficiency is different and, in general, the best wave-length for a given loop is shifted slightly toward shorter values. The reason for this is that for damped waves the reception is a function of transmitter and receiver decrements such that the inverse proportionality of current to loop resistance is not exact.

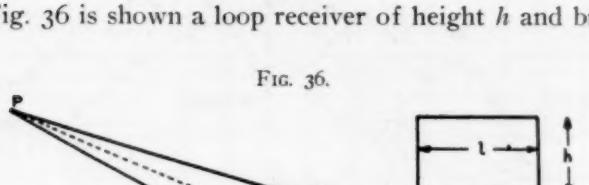
PART II.

THE DIRECTIONAL CHARACTERISTICS OF LOOP RECEIVERS.

GENERAL.

In Fig. 36 is shown a loop receiver of height h and breadth l

FIG. 36.



turned at angle α (in azimuth) to the line of propagation of waves originating at P. There are supposed to be N turns of wire on the loop wound close together, so that at any instant all of the wires on a given edge of the loop A or B occupy sensibly the same place in the wave field; in other words, the winding here is not spaced.

It is further assumed that the wave front at the receiver is plane and perpendicular to the earth's surface.

Let $e = E \sin \omega t$ = electric field intensity at O produced by P.

The field at B lags that at A by ϕ times degrees.

$$\Phi = \frac{PB - PA}{\lambda} 2\pi \text{ and since } PC \cong PA$$

$$\Phi = \frac{BC}{\lambda} 2\pi = \frac{2\pi l}{\lambda} \cos \alpha$$

At B the electric field (referred in time to o) is:

$$e_b = E \sin \left(\omega t - \frac{\Phi}{2}\right)$$

at A it is:

$$e_a = E \sin \left(\omega t + \frac{\Phi}{2}\right)$$

The instantaneous potential on each of the N wires at A is:

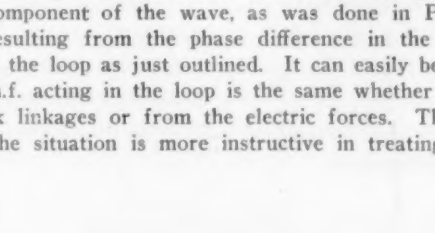
$$v_a = \int_o^h e_a \, dh = e_a h$$

On each of the wires at B it is:

$$v_b = \int_o^h e_b \, dh = e_b h$$

It is the vector difference of the potentials V_a and V_b summed for N wires which causes current to flow in the loop.[8] The vector diagram is shown in Fig. 37.

FIG. 37.



We thus have for the effective instantaneous voltage acting in the serial loop circuit

$$v_r = nv = nEh\left[\sin\left(\omega t + \frac{\Phi}{2}\right) - \sin\left(\omega t - \frac{\Phi}{2}\right)\right] = 2nEh \sin\frac{\Phi}{2}\cos\omega t$$

[8] There are two ways of thinking of the production of driving electromotive in the loop. It can be considered as being induced by the magnetic flux component of the wave, as was done in Part I, or it can be treated as resulting from the phase difference in the electric field at the two sides of the loop as just outlined. It can easily be shown that the value of the e.m.f. acting in the loop is the same whether it is derived on the basis of flux linkages or from the electric forces. The latter method of considering the situation is more instructive in treating the directional characteristics.

The amplitude of this voltage is thus

$$2nEh \sin \frac{\Phi}{2} = 2nEh \sin \left(\frac{\pi l}{\lambda} \cos \alpha \right)$$

For l much less than λ as is usually the case

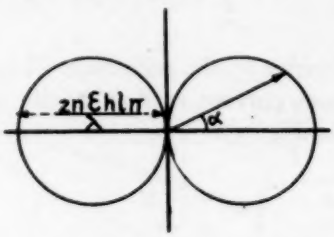
$$\sin \frac{\pi l}{\lambda} \cos \alpha \cong \frac{\pi l}{\lambda} \cos \alpha$$

and amplitude is

$$\frac{2n E h \pi l}{\lambda} \cos \alpha \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (1)$$

This is the fundamental equation for the directional characteristics of the loop and gives the two tangent circles of Fig. 38.

FIG. 38.



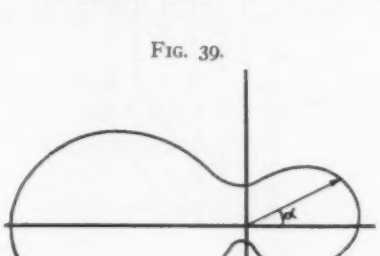
DEVIATION OF THE POLAR CURVE IN PRACTICE FROM THE DOUBLE CIRCLE DERIVED BY THE SIMPLE THEORY.

In practice the directional characteristic of the loop receiver is not so uniform as is indicated by the two tangent circles derived from the simple theory. Its shape has been found to depend in the shape and dimensions of the loop, the manner of winding, proximity to the earth's surface or nearby conductors, the nature of the terrain separating transmitter and receiver and on the arrangement and disposition of the receiving apparatus. A typical curve as obtained by measurement of received signal at different angular positions of the loop may be as shown in Fig. 39. It is seen that there may be a considerable polar dissymmetry with unequal maxima and minima, and although not always as pronounced as is indicated in the figure is nevertheless always present and when augmented by proper design of the apparatus can be readily used for determination of the *absolute* direction or *sense* of a distant transmitter.

It is the purpose of the following discussion to give the reasons for this dissymmetry. The analysis has led to the development of different means of either enhancing or decreasing it so that utility of the loop direction finder is considerably increased.

In general, there are two different types of loops in use: the solenoidal type in which all turns have the same area, and the flat pancake type in which the areas of successive turns decrease toward the centre of the winding. The two types have different directional characteristics, and each will be considered separately.

FIG. 39.



SOLENOIDAL TYPE LOOP.

The type of loop to be considered here is shown in Fig. 40. Its polar characteristic is distorted from the simple circular form, being the combination of three different effects.

1. The displacement current effect.
2. The antenna effect.
3. The shape effect.

1. *The Displacement Current Effect.*—According to the simple theory, when the plane of the loop is at right angles with the direction of wave travel, the electromotive forces developed in wires *a* and *b* are all equal and simultaneously opposite to each other in phase, so that no current flows to the tuning condenser *C*. This conclusion is correct as far as the simple loop effect is concerned, but a certain current does flow to the condenser even at the position $\alpha = 90°$ and this is in part due to what has been here termed the "displacement current effect."

On account of the spacing of the winding there is a phase difference between the voltages developed in successive wires for

FIG. 40.

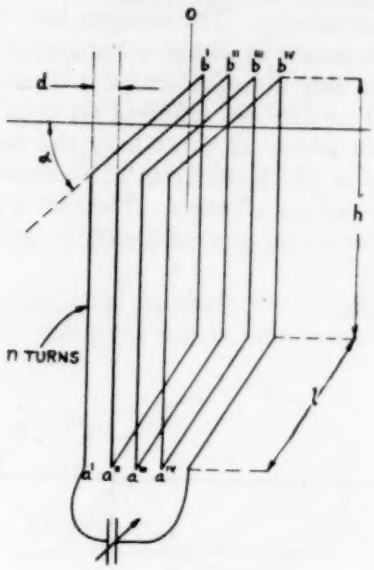
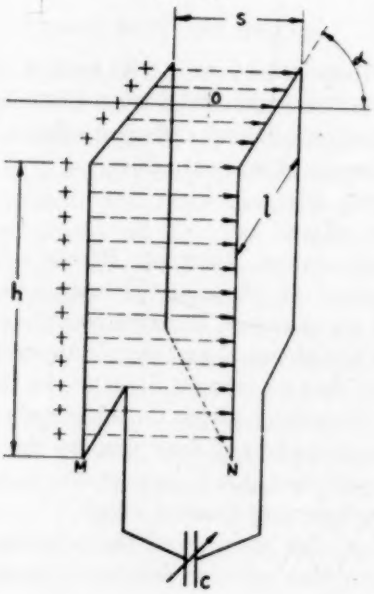


FIG. 41.



all positions except $\alpha = 0°$, and for this reason displacement currents flow across the coil through the series capacities formed by successive convolutions of the winding (see Fig. 41). This current passes out through the tuning condenser C and produces a signal.

In Fig. 41, all the turns have been omitted save the two outer ones. This simplifies the treatment considerably without introducing much error, because what we are really concerned with in any case is the total phase displacement between the first and last turns and the capacity of the $(n\text{-}1)$ condensers in series formed by the n successive turns.

If, as before, $e = E \sin \omega t$ at centre of loop O

then when the plane of the loop is at right angles to the line of wave propagation the instantaneous electric field at M is

$$e_m = E \sin \left(\omega t + \frac{\pi s}{\lambda} \right)$$

At N it is

$$e_n = E \sin \left(\omega t - \frac{\pi s}{\lambda} \right)$$

It is the difference of these two which gives rise to the displacement current between wires.

$$e = e_m - e_n = E \left[\sin \left(\omega t + \frac{\pi s}{\lambda} \right) - \sin \left(\omega t - \frac{\pi s}{\lambda} \right) \right]$$

$$= 2 E \sin \frac{\pi s}{\lambda} \cos \omega t.$$

The amplitude of this potential difference is thus

$$2 E \sin \frac{\pi s}{\lambda} \cong \frac{2 \pi s}{\lambda} E \text{ since } \frac{s}{\lambda} \text{ is very small.}$$

This expression holds when the loop is at right angles to the wave, that is, $\alpha = 90°$. For any other angular position it becomes

$$\frac{2 \pi s}{\lambda} E \sin \alpha \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (2)$$

In order to get the effect on the detector this must be integrated through the height h so that we get (this is only approximate; more accurate expression is developed below):

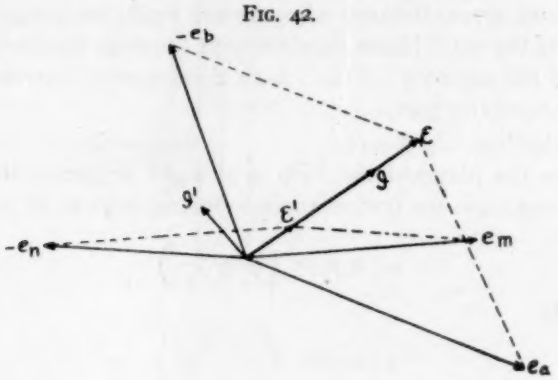
$$\frac{2 \pi s h}{\lambda} E \sin \alpha \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (3)$$

as the expression which must be compared with (1) if it is de-

sired to know the ratio of signals produced by the straight loop effect and the displacement current effect.

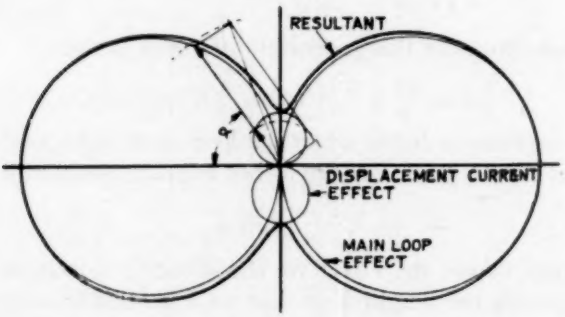
If the displacement current effect is combined with the straight loop effect the result shown in Fig. 43 is obtained. It must be noted in superposing these effects that the two must be added vectorially as at right angles to one another because the *e.m.f.*

FIG. 42.



of the direct loop effect produces current through a tuned circuit and thus in phase with itself while the second effect gives charging current 90° displaced from the voltage. The vector diagram for a given angular coil position is shown in Fig. 42.

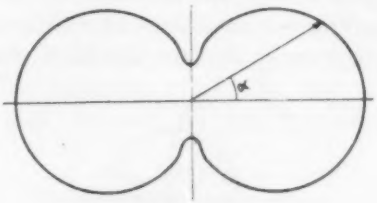
FIG. 43.



There is another displacement current effect besides that first described. It is maximum when the coil is in line with the waves, *i.e.*, in position for maximum signals, and is simply the usual

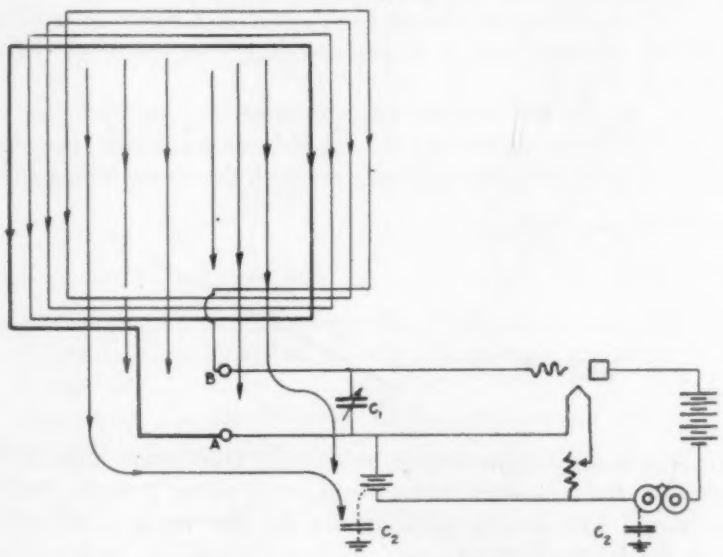
current flowing through the distributed capacity of the coil. It depends on the ratio of inductive reactance to capacity reactance per unit length of the winding, and this, of course, is small (except near the natural frequency of the coil), as is shown by the

FIG. 44.



necessity of having a condenser across the terminals for tuning. It depends, also, of course, on the linear dimensions of the coil, increasing with increase of l and H.

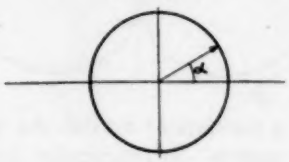
FIG. 45.



The polar curve of the effect would be that shown in Fig. 44, so that if it is taken into consideration its chief effect is to very slightly elongate the major axis of the directional characteristic, and is, therefore, not of great importance.

2. *The Antenna Effect.*—This effect is occasioned by capacity currents to earth from the loop structure acting as a simple antenna and is what produces asymmetry in the polar characteristic. Referring to Fig. 45, it is seen that a certain current flows directly between the loop and ground through the capacity of the filament battery and operator's body; and since the two terminals, A and B, of the loop have different capacities against ground a voltage is developed between them. The amplitude of this voltage is obvi-

FIG. 46.

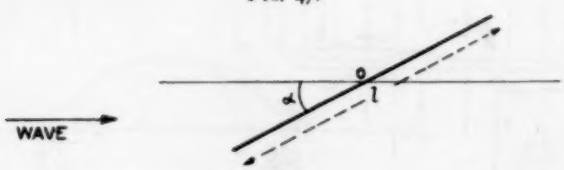


ously independent of the angular position of the loop and hence gives a circular polar characteristic, as in Fig. 46.

The magnitude of the antenna effect is difficult to calculate with any accuracy, but is measured roughly by the height of the antenna (loop).

As regards the detector effect it must be combined with the other voltages in proper phase. It produces essentially a capacity current and hence in time quadrature with the straight loop effect,

FIG. 47.



but this is only approximate because its true phase must be referred to the axis O of the loop and hence varies with the angular position. The proper angle to use for the vector combination with the other effects is

$$90^\circ \pm \frac{\pi l}{\lambda} \cos \alpha$$

as can be seen from Fig. 47.

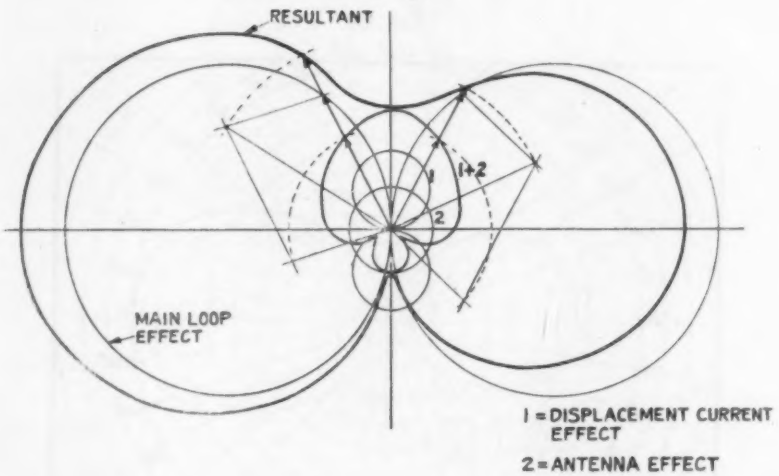
This shift in the phase of the antenna effect produces dis-

tortion in the neighborhood of both maxima and minima of the resultant polar curve where all the effects are combined.

In Fig. 48 is shown the characteristic of a solenoidal type loop as derived by the proper superposition of (1) the straight loop effect, (2) the displacement current effect, and (3) the antenna effect.

3. *The Shape Effect.*—There is an additional distortive effect caused by changes in the ratio of height to length of loop. The nature of this effect is shown in Fig. 49, where the dotted curve is derived for a high, narrow coil, and the solid line for a wide,

FIG. 48.



low coil having half the antenna effect. It is seen that a sharper maximum is to be expected from a tall, narrow coil than for a low, broad one.

The reason for the difference is that the antenna effect for a narrow coil is large and its phase

$$90^\circ \pm \frac{\pi l}{\lambda} \cos \alpha$$

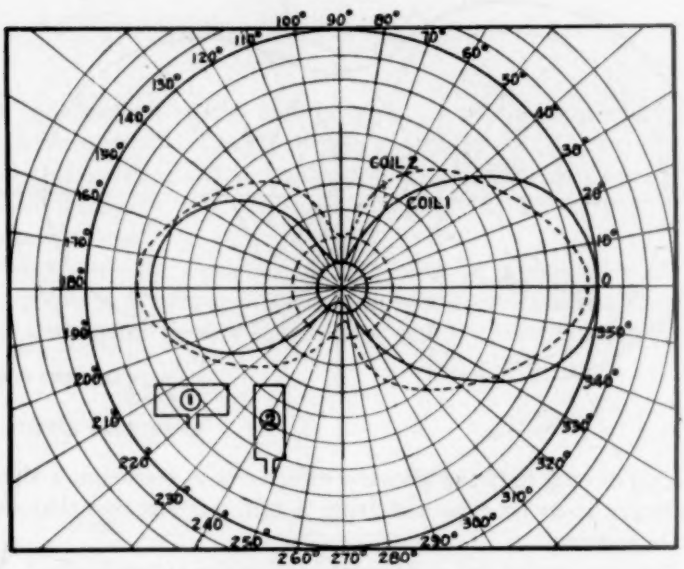
changes only slightly as the coil is turned, while for a broad coil (larger 1) the phase change is greater and since the antenna effect is less (for the same area) the curve is little distorted in the neighborhood of minima but noticeably bulged out toward the maxima.

The shape of the curves of Fig. 49 have been exaggerated for clearness but show the general shape of the total polar characteristic, and have been well checked experimentally.

IMPROVEMENT OF THE ACCURACY OF THE SOLENOIDAL TYPE LOOP AS DIRECTION FINDER.

In all cases the accuracy of the direction finder depends primarily upon obtaining a sharp minimum in the neighborhood of $\alpha = 90°$. Reference to the above discussion and the Fig. 48 shows that the sharpness of the minimum depends

FIG. 49.



1. On the magnitude of the displacement current effect,
2. On the magnitude of the antenna effect.

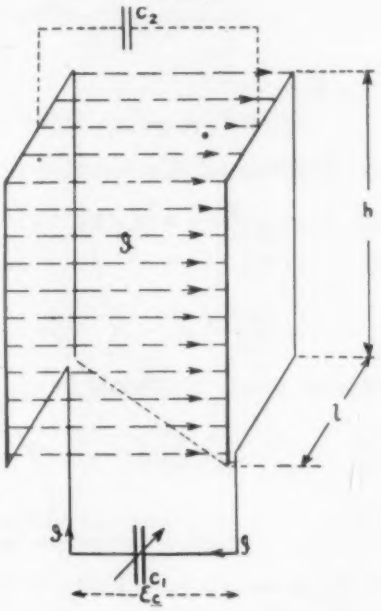
It is necessary to reduce both these effects in order to secure a sharp minimum. Both are affected by the shape of the loop. The displacement current effect for given area is minimum for a *square* loop, because this shape gives shortest possible perimetre and thereby minimum capacity between turns. The antenna effect is less for low coil, *i.e.*, small ratio of h to l.

REDUCTION OF THE DISPLACEMENT CURRENT EFFECT.

The displacement current effect can be reduced to a minimum by proper spacing of the wires constituting the winding.

We have,[9] referring to Fig. 50, which is a duplication of Fig. 41, as the voltage across the tuning condenser C_1

FIG. 50.



$$E_c = \frac{I}{\omega c}$$

where I = displacement current through the capacity C_2 of the winding.

The voltage producing the current I is, by equation (2)

$$\frac{2\pi s}{\lambda} E$$

Therefore,

$$I = \frac{2\pi s E}{\lambda} \omega \frac{C_1 C_2}{C_1 + C_2}$$

$$e = \frac{2\pi s E}{\lambda} \omega \frac{C_1 C_2}{C_1 + C_2} \cdot \frac{1}{\omega C_1}$$

$$= \frac{2\pi s E}{\lambda} \cdot \frac{C_2}{C_1 + C_2}$$

[9] This treatment is not rigid and is only intended to show approximately what can be accomplished by proper spacing of the winding.

or

$$E_e = K \frac{s\, C_2}{C_1 + C_2}$$

Now C_2 is the capacity between parallel wires of length $2(h+l)$ diameter d, and separation s and is

$$C_2 = \frac{1}{n-1} \cdot \frac{2\,(h+l)}{2 \log_e \frac{2s}{d(n-1)}} \text{ cms.}$$

Hence

$$E_e = K \frac{s\,(h+l)}{(n-1)\, C_1 \log \frac{2s}{d(n-1)} + (h+l)} \quad \ldots\ldots\ldots\ldots (5)$$

The condition for minimum of this function is

$$\frac{d\,E_e}{ds} = o = \left[(n-1)\, C_1 \log \frac{2s}{d(n-1)} + (h+l)\right](h+l) - (n-1)\, C_1\,(h+l)$$

or

$$s = \frac{d(n-1)}{2} \epsilon^{1 - \frac{h+l}{(n-1)\, C_1}}$$

or the spacing between wires $\frac{s}{n-1}$ should be

$$\frac{d}{2} \epsilon^{1 - \frac{h+l}{(n-1)\, C_1}} \quad \ldots\ldots\ldots\ldots\ldots (6)$$

$\cong 1.4d$ ..... for a many turn winding or where the wave-length is very long so that C_1 is large.

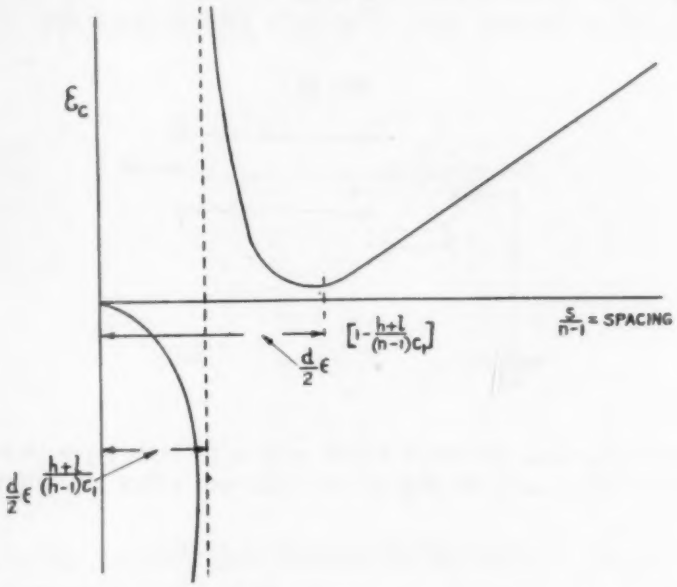
The function (5) is shown graphically in Fig. 51. That is, this figure shows the variation in the magnitude of the displacement current effect with spacing $\frac{s}{n-1}$.

These deductions are of particular value in designing coils for long wave-length work where a large number of turns will be used. For short wave-lengths only a few turns are used and the displacement current is then small in any case, so that usually overall efficiency is more important than the reduction of the displacement currents. For this reason on coils for this class of work using only a few turns the wires will usually be spaced somewhat further apart than the value given by $1.4d$ or (6). As regards long wave-lengths, it was shown in Part I. that the spacing of the wires has not much to do with the efficiency, and hence for such cases a closer spacing may be used, as indicated by $1.4d$, and thus improve the direction finding qualities.

REDUCTION OF THE ANTENNA EFFECT.

As discussed above, the antenna effect is due to capacity currents to ground from the loop through the tuning condenser. In order to eliminate these currents it is necessary that the terminals of the loop, A and B (Fig. 45), have exactly equal capacities against ground. The condition can be partially achieved by raising the filament lighting battery of the receiver well off the ground.

FIG. 51.



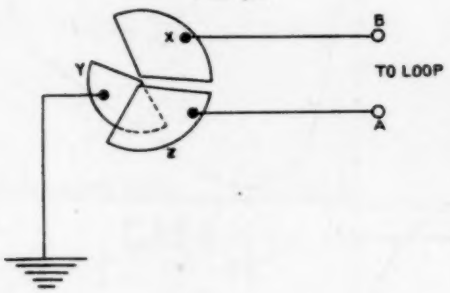
This can never be entirely satisfactory, however, because of the capacity of the operator's body through the telephone (see Fig. 45). If it is desired to obtain complete balance, an auxiliary capacity must be provided from terminal B to ground. The compensator shown in Fig. 52 can be used for this purpose. It consists of three metal plates, x, y, z, two of which, x and z, are stationary and connected respectively to the loop terminals A and B. The third plate, y, is movable and connected to earth. By turning this plate, an exact balance can be obtained for capacity to earth from the loop terminals, and the minimum in the polar curve is thereby sharpened.

Another way in which the antenna effect can be reduced in any loop and the minimum thereby sharpened is by placing a grounded electrostatic shield consisting of several horizontal wires above the loop. The theory would indicate that such arrangement makes for a more symmetrical system electrically and thus excludes, or at least greatly reduces, distortion of the characteristic.

FLAT PANCAKE LOOP.

The flat pancake type loop acts in a somewhat different way from the solenoidal type. The same general discussion of the

FIG. 52.



simple loop and the shape effect applies to both types, but the antenna effect and the displacement current effect are different.

DISPLACEMENT CURRENT EFFECT.

The main displacement current effect described above is entirely absent in the pancake loop. This is easily understood by considering the loop in the 90° position, *i.e.*, at right angles to the sending station. In this position there is no phase displacement between the electric fields acting on the several wires and hence no displacement current.

ANTENNA EFFECT.

The antenna effect is much the same as in the solenoidal type loop, but greater due to the decrease in length of the vertical wires toward the centre of the winding. Instead of being meas-

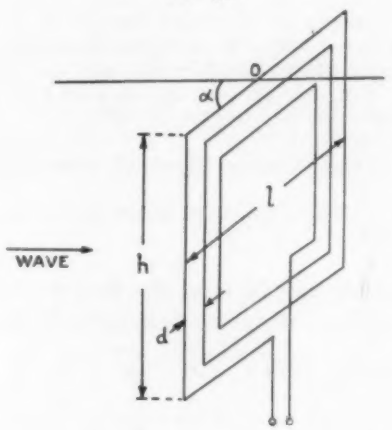
ured by the height h of the loop as for the solenoid, it is here measured approximately by

$h+2nd$
where N = number of turns
d = spacing between turns.

(See Fig. 53.)

As in the case of the solenoid, the polar amplitude curve of the antenna effect is circular, and in combining its radius vectors with those representing the straight loop effect proper recognition must be taken of the time phase angle between the two. The phase of the antenna effect varies with the azimuth of the loop

FIG. 53.



as for the solenoid and referred to the axis of the loop is approximately

$$90^\circ \pm \frac{\pi l}{\lambda} \cos \alpha$$

STRAIGHT LOOP EFFECT.

Referring to Fig. 53, let

v = Total effective instantaneous potential of straight loop effect in loop for any angular position (azimuth).

$$v = E\left\{h \sin\left(\omega t + \frac{\pi l}{\lambda} \cos \alpha\right) - (h-d) \sin\left(\omega t - \frac{\pi l}{\lambda} \cos \alpha\right)\right.$$
$$\left. + (h-2d) \sin\left(\omega t + \frac{\pi(l-2d)}{\lambda} \cos \alpha\right) - (h-3d) \sin\left(\omega t - \frac{\pi(l-2d)}{\lambda} \cos \alpha\right)\right.$$

$$+ (h-4d)\sin\left(\omega t + \frac{\pi(l-4d)}{\lambda}\cos\alpha\right) - (h-5d)\sin\left(\omega t - \frac{\pi(l-4d)}{\lambda}\cos\alpha\right)$$

$$+ (h-6d)\sin\left(\omega t + \frac{\pi(l-6d)}{\lambda}\cos\alpha\right) - (h-7d)\sin\left(\omega t - \frac{\pi(l-6d)}{\lambda}\cos\alpha\right)$$

$$+ \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots$$

$$+ (h-2(n-1)d)\sin\left(\omega t + \frac{\pi(l-2(n-1)d)}{\lambda}\right)\cos\alpha$$

$$-(h-(2n-1)d)\sin\left(\frac{\omega t - \pi(l-2(n-1)d)}{\lambda}\cos\alpha\right)\Bigg\}$$

Let

$$\frac{\pi\cos\alpha}{\lambda} = k$$

$$\omega t = \theta$$

$$v = \Bigg\{ h\sin\theta\cos kl + h\cos\theta\sin kl - (h-d)\sin\theta\cos kl + (h-d)\cos\theta\sin kl$$
$$+ (h-2d)\sin\theta\cos k\,(l-2d) + (h-2d)\cos\theta\sin k\,(l-2d) - (h-3d)\sin\theta\cos$$
$$k\,(l-2d) + (h-3d)\cos\theta\sin k(l-2d)$$
$$+ (h-4d)\sin\theta\cos k(l-4d) + (h-4d)\cos\theta\sin k\,(l-4d) - (h-5d)\sin\theta$$
$$\cos k\,(l-4d) + (h-5d)\cos\theta\sin k(l-4d)$$
$$+ \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots$$
$$+ [h-2\,(n-1)\,d]\sin\theta\cos k\,(l-2\,(n-1)d) + [h-2\,(n-1)\,d]\cos\theta\sin k$$
$$(l-2(n-1)d)$$
$$- [h-(2b-1)d]\sin\theta\cos k(l-2.(n-1)d) + [h-(2\,n-1)\,d]\cos\theta\sin k$$
$$(l-2(n-1)d)\Bigg\}$$

As approximation can be used the first two terms of the cos and sin expansions into series by Maclaurin's theorem.

$$\sin x = x - \frac{x^3}{L^3}$$

$$\cos x = 1 - \frac{x^3}{L^2}$$

Now

$\frac{l}{\lambda}$ is never > 0.01

$$\therefore \quad \cos kl = \cos\frac{\pi l}{\lambda}\cos\alpha \cong 1$$

$$\sin kl \cong kl = \frac{\pi l}{\lambda}\cos\alpha$$

Hence

$$v\,E\Bigg\{ h\sin\theta + hkl\cos\theta - (h-d)\sin\theta + (h-d)\,kl\cos\theta$$
$$+ (h-2d)\sin\theta + (h-2d)\,k(l-2d)\cos\theta - (h-3d)\sin\theta + (h-3d)\,k$$
$$(l-2d)\cos\theta$$
$$+ (h-4d)\sin\theta + (h-4d)\,k\,(l-4d)\cos\theta - (h-5d)\sin\theta + (h-5d)\,k$$
$$(l-4d)\cos\theta$$
$$+ \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots$$
$$+ [h-2\,(n-1)d]\sin\theta + [h-2\,(n-1)\,d]\,k\,(l-2\,(n-1)d)\cos\theta$$
$$- [h-(2n-1)d]\sin\theta + [h-(2n-1)d]\,k(l-2(n-1)d)\cos\theta\Bigg\}$$

$$= E\Big\{\Big[h-(h-d)+(h-2d)-(h-3d)+(h-4d)-(h-5d)+\ldots\ldots\ldots\ldots\ldots\ldots +(h-2(n-1)d)-(h-(2n-1)d)[\sin\theta\Big]$$

$$\Big[k+hl+(h-d)l+(h-2d)(l-^2d)+(h-3d)(l-^2d)+(h-4d)(l-4d) +(h-5d)(l-4d) +\ldots\ldots\ldots+[h-2(n-1)d][l-^2(n-1)d]+[h-(2n-1)d][l-^2 (n-1)d]\Big]\cos\theta\Big\}$$

$$= E\Big\{d\Big[1-2+3-4+5-\ldots\ldots\ldots-2(n-1)+(2n-1)\Big]\sin\theta +k\Big[hl+hl-dl+hl-2dl-^2hd+4d^2+hl-3dl-^2hd+6d^2+hl-4dl-4dh+ 16d^2+hl-5dl-4dh+20d^2+\ldots\ldots\ldots\ldots\ldots\ldots +hl-2(n-1)dl-2(n-1)dh+4(n-1)^2d^2+hl-(2n-1)dl-^2(n-1)dh+^2 (2n-1)(n-1)d_2\Big]\cos\theta\Big\}$$

$$= E\Big\{nd\sin\theta+k\Big[2nhl-dl(1+2+3+4+5+\ldots\ldots\ldots 2(n-1)+(2n-1) -2hd(1+1+2+2+\ldots\ldots(n-1)+(n-1) +2d^2(2+3+8+10+\ldots\ldots 2(n-1)^2+(2n-1)(n-1))\Big]\cos\theta\Big\}$$

$$= E\Big\{nd\sin\theta+k\Big[2nhl-n(2n-1)dl-2n(n-1)dh +2d^2\big(2+3+8+10+\ldots\ldots 2(n-1)^2+(2n-1)(n-1)\big)\Big]\cos\theta\Big\}$$

$$\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(7)$$

$$v = nE\Big\{\sqrt{d^2+k^2\Big[2hl-(2n-1)dl-2(n-1)dh+\frac{2d^2}{n}(2+3+8+10+\ldots\ldots\ldots 2(n-1)^2+(2n-1)(n-1)\Big]^2}\sin(\theta+\gamma)\Big\} \quad\ldots\ldots\ldots\ldots\ldots\ldots(8)$$

where

$$\gamma=\tan^{-1}\frac{k\Big[2h-(2n-1)dl-2(n-1)dh+\frac{2d^2}{n}(2+3+8+10+\ldots\ldots 2(n-1)^2(+(2n-1)(n-1)\Big]}{d}\quad\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(9)$$

Equations (7), (8) and (9) show that the straight loop effect of the pancake may be thought of as made up of two parts to be added vertorially at 90°. One of these,

$$n\,d\,E$$

is independent of angular position and therefore circular; the other,

$$k\Big[2hl-(2n-1)dl-2(n-1)dh+2\frac{d^2}{n}(2+3+8+10+\ldots.2(n-1)^2+ (2n-1)(n-1))\Big]$$

varies according to k, *i.e.*, the cosine of the angle, and hence appears as two tangent circles. The phase γ of the resultant of these referred to the loop axis varies also with Cos α. The

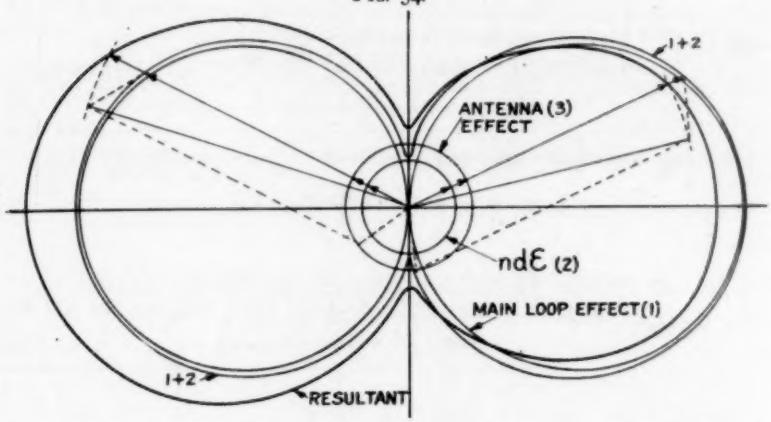
angle to be used, therefore, in combining the antenna and straight loop effect is

$$T = \gamma \pm \left(90^\circ + \frac{\pi l}{\lambda}\cos\alpha\right)$$

$$Tan^{-1} = 90^\circ \pm \frac{\pi \cos \alpha}{\lambda}\left[2hl-(2n-1)dl-2(n-1)dh+\frac{2d^2}{n}(2+3+8.....)+l\right]$$

It is seen from this expression that the angle T at which the antenna effect and the direct loop effect must be combined changes with different angular coil positions. This is a very significant circumstance. It gives rise to distortion of the polar curve which is particularly noticeable in the neighborhood of maxima. In the pancake loop it is not essentially the cause of a broader mini-

FIG. 54.



mum on one side of the curve than on the other. This is due to a combination of the antenna effect with the second displacement current effect mentioned under the solenoid loop, which latter has its maximum value when $\alpha = 0$.

Fig. 54 is drawn to show the various effects in a pancake loop and their resultant. The shape effect is not shown, but, as has been explained, tends principally to elongate the curve along the major axis. The second displacement current effect is also omitted for simplicity, thus giving symmetrical minima.

FACTORS AFFECTING DISTORTION AND SHARPNESS OF MINIMUM.

The sharpness of the minimum can be increased by decreasing the term n [see equation (7)]; that is, by decreasing the radial

depth of the winding. It can be further increased by decreasing the antenna effect; that is, by decreasing the wire spacing or by any of the means described for the solenoid loop. This also reduces dissymmetry in the characteristic.

When the dissymmetry is desirable as for finding *absolute* direction, the pancake type winding should always be used and the antenna effect increased by any means possible. A rather wider spacing of the wires is, therefore, desirable in this case than would ordinarily be used on a solenoid loop.

Increasing the spacing must not be carried to extreme, however, since it seriously impairs the accuracy of the coil as direction finder by broadening the minimum.

It is, in fact, true and a point of practical interest that the pancake loop usually never has as sharp minimum as the solenoidal type, because, even for equal antenna effects in the two cases, the displacement current effect in the solenoid, measured by

$$\frac{2\pi s E}{\lambda}$$

is much smaller than the equivalent " winding " pitch effect of the pancake which depends on

$$n d E$$

In regard to this statement it should be pointed out that the theoretical characteristics for the two types of loops (Figs. 48, 49 and 54) are not drawn to scale nor with the exact distortion angles, so that they cannot be compared with each other. Tendencies only are indicated.

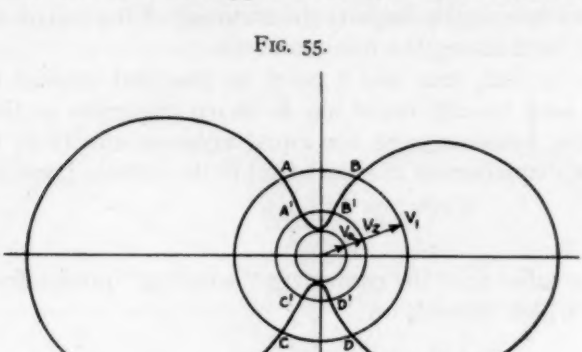
EFFECT OF RECEIVER SENSITIVENESS NECESSITY FOR RADIO FREQUENCY AMPLIFICATION.

The accuracy of the direction finder and the speed with which settings can be made depend on the sharpness of the minimum points in the directional polar characteristic. Some of the factors that effect this have just been discussed, but there is in addition to these another very important one, namely, the sensitiveness of the detecting apparatus.

If the sensitiveness is made very great, it is often difficult to find an absolute zero as the loop is rotated. It will sometimes only be possible to find a more or less restricted region of minimum signal strength, the reasons for which are evident from the

figures and the discussion above. Nevertheless, it is generally desirable to have the detection sensitiveness as great as possible for the following reason: If the polar curve is as shown in Fig. 55 and the sensitiveness of the detecting apparatus is such that it just responds to the potentials of value V_1, and voltages less than this cannot be detected, then as the loop is rotated zero response will be obtained through the regions AB and CD. If, however, the detector sensitiveness is greater so that smaller voltages down to value V_2 can be detected the zero regions are narrowed down to $A'B'$ and $C'D'$ and the apparatus becomes more accurate. By

FIG. 55.



further increasing the sensitiveness still greater accuracy is obtained as the zero regions are further narrowed and, in the case shown, an increase in sensitiveness to correspond to the potential V_0 would give a single point or position where there would be zero response.

It is very desirable to produce this condition, but to do so requires extremely sensitive detecting apparatus as well as a very sharp antenna (loop) characteristic. If the zero regions are wider than a few degrees so that they cannot be accurately and quickly bisected experimentally, the average of the four readings, A, B, C, D, where the signal becomes inaudible must be taken as an indication of the true minimum, and although this requires time, it has, nevertheless, been found to give good accuracy provided the regions of silence do not exceed about 30°. With the

uncompensated loop midpoints of the regions *AB* and *CD* are not 180° apart, as has already been shown, and this makes it necessary to average all four readings as just described.

On account of the exponential relation between current passed and applied potential, all the usual radio detectors respond much more effectively to large impressed voltages, that is strong signals, than they do to weak ones. In other words, the ordinary detector (including the vacuum tube) is insensitive to weak signals, and since it is always in the region of weak signals that the directional setting is made there is a great loss of accuracy. No amount of audio frequency amplification will overcome the difficulty because the audio frequency amplification cannot be brought into play until the detector is "triggered off." It is for these reasons that it has been found necessary to amplify the radio frequency energy before passing it to the detector by means of a multistage radio frequency amplifier.

PART III.

EXPERIMENTAL CHECKING OF RESULTS AND PRACTICAL FORMS OF APPARATUS DEVELOPED.

Space does not permit a full account of the large number of experiments that have been made to check the conclusions arrived at from the above theoretical considerations, nor of those made for the purpose of amplifying the theory and gathering certain additional data necessary for the actual design of apparatus. Neither is it possible here to fully cover descriptions of the various types of loops, loop connections, and associated apparatus that have been developed for special uses. Suffice it to say that continuous experimental effort has been carried on for more than a year following and paralleling the theoretical deductions and not only has the theory been substantiated in every respect but several important applications suggested by the theory have been reduced to practice in a very gratifying way. The present section is divided into three parts:

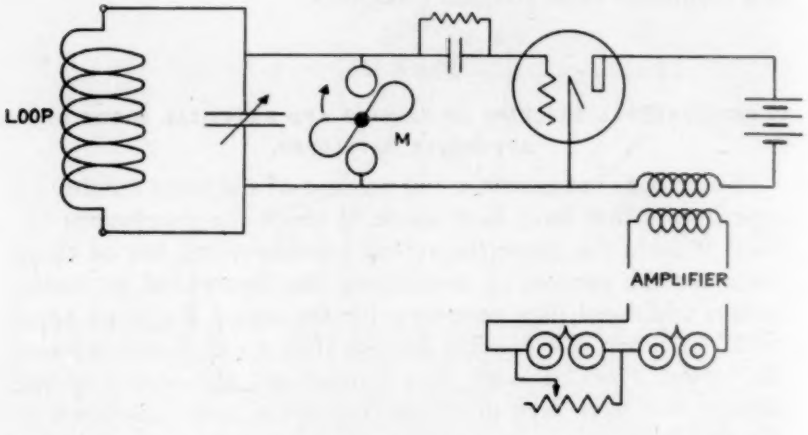
1. Examples and method of checking design data of Part I.
2. Experimental verification of Directional Characteristics and improvement of same.
3. Special developments and uses.

I.

METHODS USED IN VERIFYING DESIGN DATA OF PART I.

In order to check the results of Part I, giving data on the design of loops from the standpoint of high receiving efficiency, a number of measurements were made of received signal strength in actual undamped wave transmissions. For this purpose a vacuum tube transmitter with antenna was set up 1/5 mile distant from the loop receiver to be tested and the signal at the receiving end measured on various loops at different wavelengths by the shunted telephone method. The current in the transmitting antenna was adjusted to the same value at all wavelengths by means of a variable resistance placed in the antenna circuit.

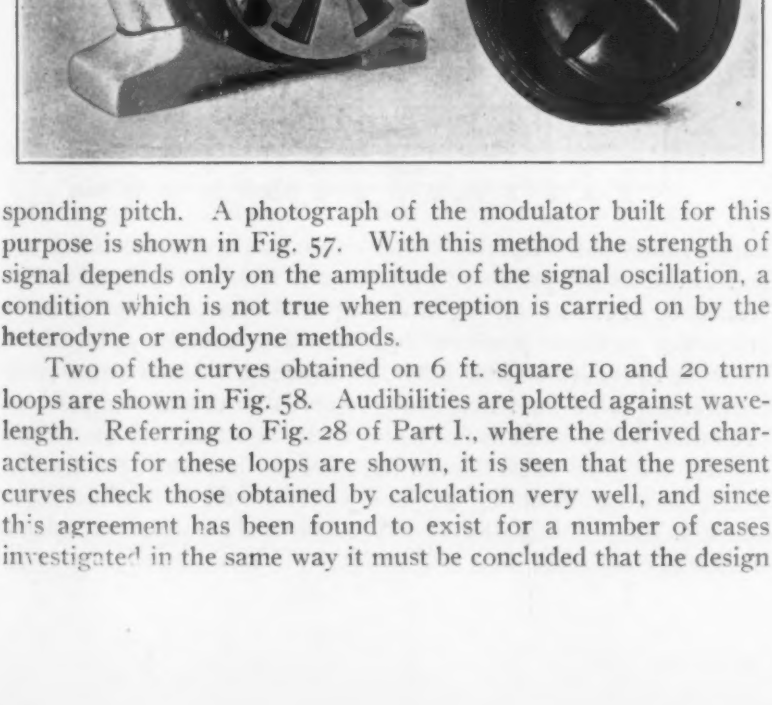
FIG. 56.



The arrangement of receiving apparatus in most of the experiments was that shown in Fig. 56. An ordinary non-oscillating detector tube with a multistage amplifier is connected to the tuned loop circuit in the usual way across the variable condenser. In order to get audible response from the incoming undamped oscillations the modulator M is connected across the main tuning condenser. This modulator consists of a set of stationary sectored metal discs and insulated therefrom another set of similarly sectored movable discs fastened to the shaft of a small electric motor. The device thus constitutes a condenser whose

capacity varies continuously from its minimum through its maximum values as the motor rotates. The number of sectors and the speed of rotation is so chosen that the variation of capacity through the extreme values occurs at an audible rate of, say, 300 or 400 times a second. The tuning condenser is adjusted somewhere near to the value of capacity required to tune to the incoming signals; then as the modulating condenser revolves the system is alternately brought into and out of tune at an audible rate by it and the gushes of energy fed to the detector each time resonance is reached cause a signal in the telephones of corre-

FIG. 57.



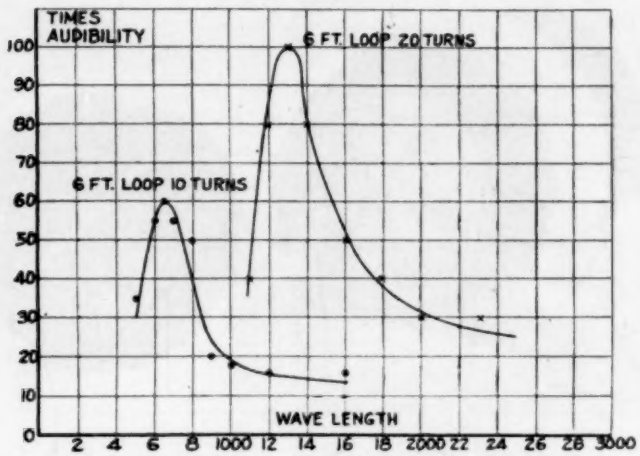
sponding pitch. A photograph of the modulator built for this purpose is shown in Fig. 57. With this method the strength of signal depends only on the amplitude of the signal oscillation, a condition which is not true when reception is carried on by the heterodyne or endodyne methods.

Two of the curves obtained on 6 ft. square 10 and 20 turn loops are shown in Fig. 58. Audibilities are plotted against wavelength. Referring to Fig. 28 of Part I., where the derived characteristics for these loops are shown, it is seen that the present curves check those obtained by calculation very well, and since this agreement has been found to exist for a number of cases investigated in the same way it must be concluded that the design

data of Part I. are satisfactorily representative of the performance of the loops which it is intended to cover.

A word should be said further with regard to reception on the heterodyne or endodyne principles. In the former case where a separate local oscillator is used at the receiver to produce beats with the incoming signal oscillation the functioning of the apparatus does not involve any essentially different points other than those already considered. The larger the voltage impressed on the detector by the incoming oscillation the stronger will be the signal, other adjustments of local oscillation being properly made in every case. In the case of endodyne reception where the receiving circuits are themselves oscillating, conditions are ordi-

FIG. 58.

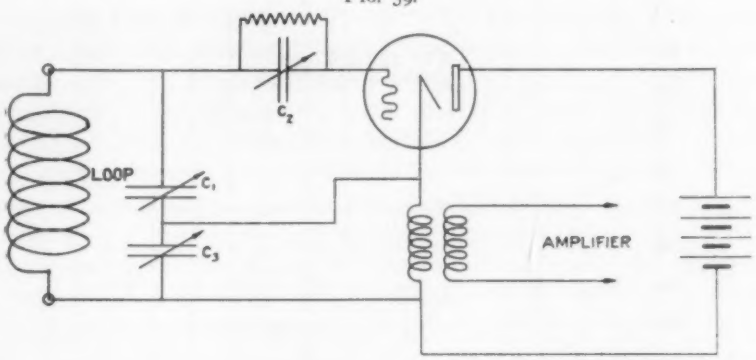


narily somewhat different. The impedance of the receiving circuit to the locally produced oscillation is zero and is equal to the resistance of the circuit for incoming oscillations having the same frequency as those produced locally. It is necessary, however, in order to secure audible beats, to adjust the local frequency to a different value than that being received so that the impedance presented to the latter is not equal to the resistance of the circuit but has a higher value depending upon the amount of detuning. The percentage detuning obviously varies with the wave-length and with the note it is desired to produce in the telephones, so that the energy collected does not ordinarily follow exactly the same

variation with wave-length as with the separate heterodyne or with the non-oscillating receiver. At long waves a considerable loss in efficiency results from the large amount of mistuning necessary to get audible beat frequencies. The overall efficiency also depends upon the way in which the receiving circuit is oscillating, upon the ratio of the strength of its oscillations to those of the incoming wave, so that the matter is very complex and, as just stated, the best signals for a given loop may not necessarily come exactly at the wave-lengths indicated in the charts; but their location depends a good deal on the particular adjustment used.

To illustrate the characteristic reception obtained by the endodyne method several curves were taken on different loops using

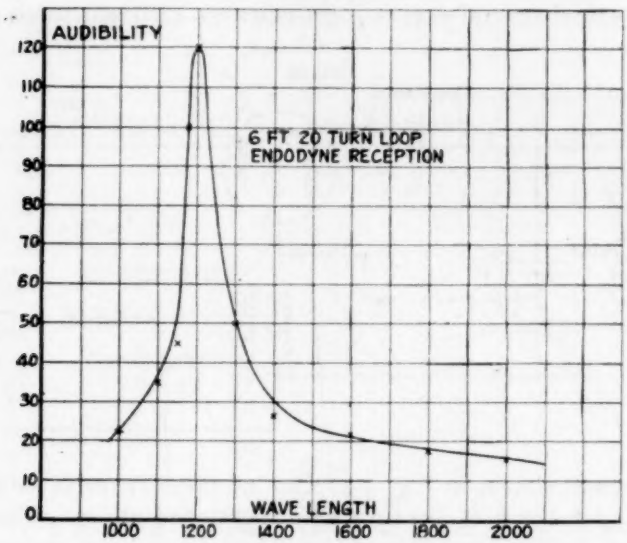
FIG. 59.



the receiver shown in Fig. 59. One of these cuves is shown in Fig. 60 for the 6 ft. 20 turn loop mentioned above. The beat pitch was held constant for all wave-lengths and was rather high (about 800 cycles per second) corresponding closely to the natural vibration rate of the telephone receiver diaphragms. Condenser C_3 was kept fixed and the adjustments were made each time with the tuning condenser C_1 and the grid condenser C_2. The curve shows that the best reception for the loop, under the conditions of the test, comes at about 1200 metres instead of 1300 metres as in the case of non-oscillating reception, and that the shape of the curve is different. The latter circumstance, and in particular the rapid falling off for wave-lengths longer than the optimum value, is due in large part to the mistuning required to produce the beat note.

It is possible to considerably increase the efficiency of this type of receiver and to more nearly match its performance with the predicted curves by coupling the oscillating detector inductively with the loop circuit so that the entire system has two free electrical periodicities separated by an amount corresponding to the desired beat frequency. One of these periodicities can be made equal to that of the incoming oscillations, while the other corresponds to the local beating frequency. In this way the impedance

FIG. 60.



of the circuit to the incoming oscillation is equal to its resistance and the voltage produced at the detector by this oscillation, therefore, follows such variations as have already been delineated for the non-oscillating or separate heterodyne cases. A third tuned circuit coupled to the ordinary loop receiving circuit may be used for the same purpose and with similar results.[10]

[10] No correction was made in above experiments for change in radiation resistance at transmitting antenna with wave-lengths. The antenna was very low, however, and radiation resistance therefore practically constant for the wave-lengths.

II.

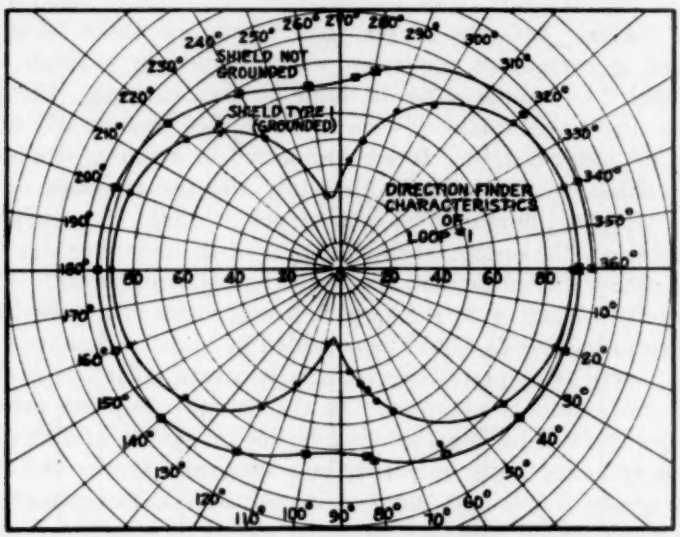
EXPERIMENTAL CHECKING OF DIRECTIONAL CHARACTERISTICS AND IMPROVEMENT OF SAME.

Several methods have been used for investigating experimentally the directional characteristics of loop antennas. One of these which has given dependable results is the following: A 10 watt vacuum tube transmitter is connected to a small antenna of any of the orthodox types and furnishes a source of electromagnetic waves. In some of the tests which are about to be described a current of 1.0 amp. was obtained in a single wire inverted "L" antenna 20 ft. high by 100 ft. long. The loop whose directional qualities were to be studied was set up, in this case, 1.6 miles distant. It was connected to a tuning condenser and oscillating vacuum tube detector, and the response of the latter was then amplified by four stages of audio frequency amplification. The output of the last tube of the amplifier was used to actuate a thermoelement connected to a galvanometer. Thus, the energy picked up by the loop, as it was rotated through different azimuthal angles, could be recorded by visual indications and with a very little practice extremely accurate polar curve characteristics could be obtained. In the actual set-up the thermoelement was one having 197 ohms heater resistance, and 12 ohms couple resistance, and operating in a vacuum. It was fed from the low side of a 30,000 ohm to 200 ohm step down repeater coil. This repeater coil with the particular values of impedance stated was used in order to match the amplifier tube internal output impedance on the high side, and the thermo-couple impedance on the low side and thus get maximum output. The galvanometer used took the form of a single pivot Paul micrometer giving full scale deflection for 360 micro-amps. Considerable trouble was at first experienced, due to howling of the four stage amplifier, but this was finally overcome by careful wiring and proper disposition of the apparatus. A large number of polar curve characteristics has been taken, using this set-up, of various loops under nearly every conceivable condition and some of the conclusions arrived at are summarized below.

Of particular interest is the study that was made of the possibility of sharpening the minimum and increasing the symmetry of the characteristic by using overhead electrostatic shields as

proposed in the theoretical discussion of Part II above. Twenty-seven different curves were taken in this investigation, covering different designs of shields and arranged differently with respect to their distance from the loop.[11] A few of these curves are reproduced herewith to indicate the actual practical improvement obtainable in the loop direction finder through the use of correctly arranged shield superstructure. In Fig. 61 are shown the

FIG. 61.



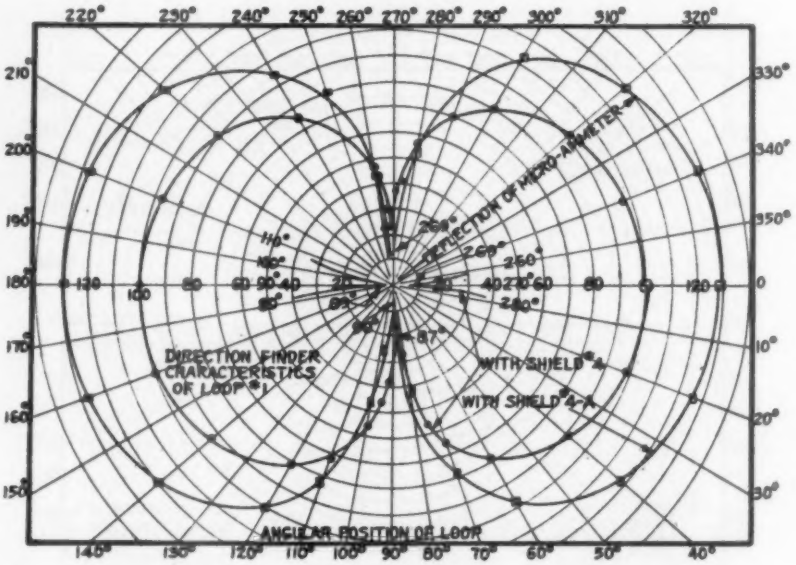
characteristics of a 5 ft. square solenoid type loop having 6 turns of No. 18 wire spaced 3/8" apart, both with and without a shield. The shield in this case took the form of a 5 ft. flat pancake wound loop, 3" between turns, mounted on top of the vertical receiving loop with one of its diagonals coincident with the top of the vertical loop and its plane parallel to the earth. The shield was, of course, grounded. It is seen that a much sharper minimum is obtained with the shield than without it.[12]

[11] The data of these tests were taken by 2nd Lieutenant Leon T. Wilson, Signal Corps.

[12] It should be noted that all of these curves would be elongated along the major axis were it not that strong signals are not amplified as much as weak ones in the apparatus used due to the curvature of the amplifier characteristic.

The curves of Fig. 62 were taken on the same 5 ft. 6 turn loop with two other type shields. These shields consisted of a harp of 24 No. 16 parallel wires 5¾ ft. long spaced ¾″ apart and held in horizontal plane ¾″ above the loop. The odd numbered wires were all joined together at their middle and the even numbered wires were similarly connected. When all of the wires were used this shield was called No. 4, and when half the wires were used it was called No. 4-A. The loop was set up on a farm near Lincroft, New Jersey. The complete curves were taken on different days.

FIG. 62.

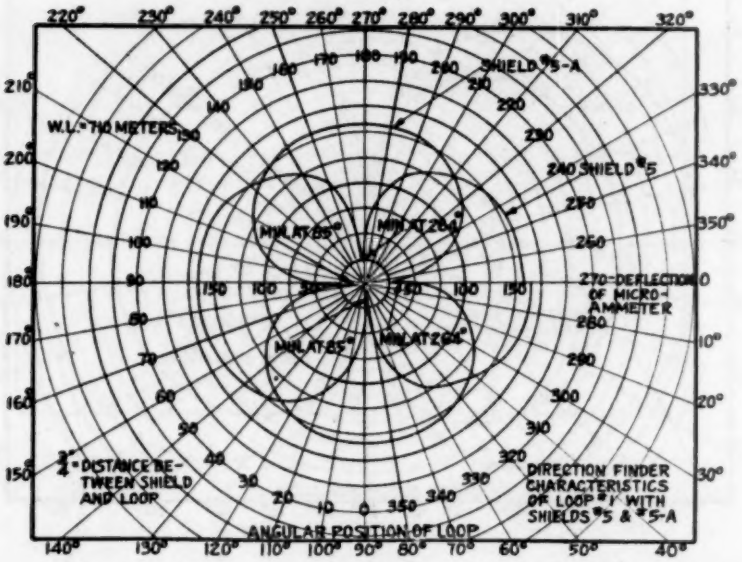


The curve for shield No. 4 was taken with 650 metres and No. 4-A with 710 metres wave-length. The small No. 4 curve and the No. 4-A curve were taken on the same morning and are comparable. It is seen from the curves that shield No. 4 has slightly better shielding qualities than shield No. 4-A, and that the minima are practically 180° apart. The minima checked with the actual direction of the station, being exactly at right angles thereto. The curves show a difference in the sharpness of the minima obtained with shield No. 4 on the two days. This is probably due to the different wave-lengths used and different weather condi-

tions, both of which factors influence the magnitude of the antenna effect.

Still two other shields were used, which were built exactly like No. 4 and No. 4-A, except that there was a total of thirty-five 6 foot long wires spaced 1″ apart. The shields were designated No. 5 and No. 5-A for the 1″ and 2″ spacing, respectively, which was provided in the same way as on shields No. 4 and No. 4-A. The curves for these two shields are shown in Fig. 63. They show that little is to be gained by using the one inch spacing instead of the two inch spacing, a result which checks the performance of shields No. 4 and No. 4-A.

FIG. 63.



Figs. 64 and 65 give an idea of the undesirable effect on the minima caused by extra capacity to ground furnished by the operators wearing the head telephones.

Fig. 66 shows the curves obtained with different distances between the loop and shield. The best distance for shield No. 5 appears to be about ¾″.

Fig. 67 shows a curve taken very near to and partly under a tree. The minima are broadened somewhat and there is a slight distortion.

FIG. 64.

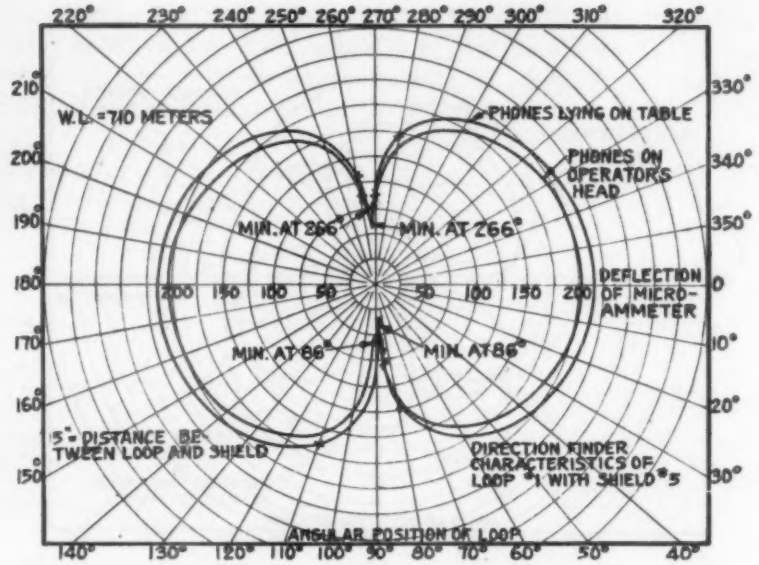

220° 230° 240° 250° 260° 270° 280° 290° 300° 310° 320°
210° 200° 190° 180° 170° 160° 150°
330° 340° 350° 0 10° 20° 30°
W.L. = 710 METERS
PHONES LYING ON TABLE
PHONES ON OPERATOR'S HEAD
MIN. AT 266°
MIN. AT 266°
200 150 100 50
50 100 150 200
DEFLECTION OF MICRO-AMMETER
MIN. AT 86°
MIN. AT 86°
5" DISTANCE BETWEEN LOOP AND SHIELD
DIRECTION FINDER CHARACTERISTICS OF LOOP "1 WITH SHIELD "5
ANGULAR POSITION OF LOOP
140° 130° 120° 110° 100° 90° 80° 70° 60° 50° 40°

FIG. 65.

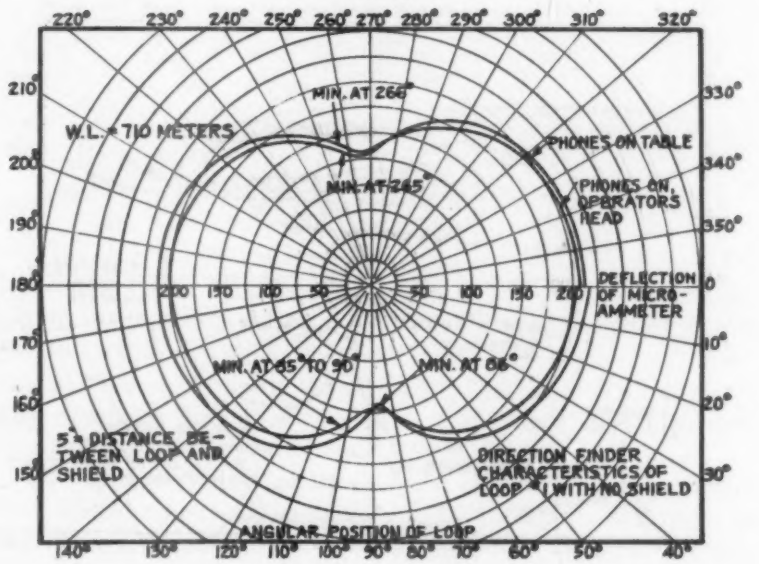

220° 230° 240° 250° 260° 270° 280° 290° 300° 310° 320°
210° 200° 190° 180° 170° 160° 150°
330° 340° 350° 0 10° 20° 30°
MIN. AT 266°
W.L. = 710 METERS
PHONES ON TABLE
MIN. AT 265°
PHONES ON OPERATORS HEAD
200 150 100 50
50 100 150 200
DEFLECTION OF MICRO-AMMETER
MIN. AT 85° TO 90°
MIN. AT 86°
5" DISTANCE BETWEEN LOOP AND SHIELD
DIRECTION FINDER CHARACTERISTICS OF LOOP "1 WITH NO SHIELD
ANGULAR POSITION OF LOOP
140° 130° 120° 110° 100° 90° 80° 70° 60° 50° 40°

FIG. 66.

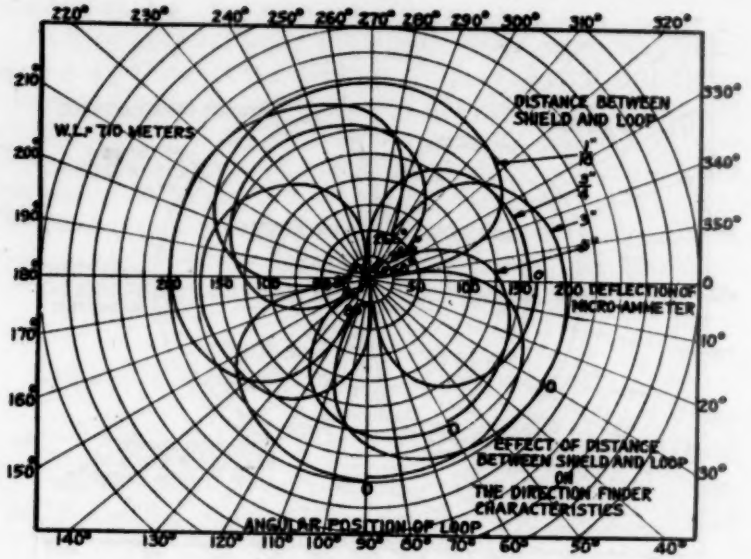

W.L. = 710 METERS
DISTANCE BETWEEN SHIELD AND LOOP
200 DEFLECTION OF MICRO-AMMETER
EFFECT OF DISTANCE BETWEEN SHIELD AND LOOP ON THE DIRECTION FINDER CHARACTERISTICS
ANGULAR POSITION OF LOOP

FIG. 67.

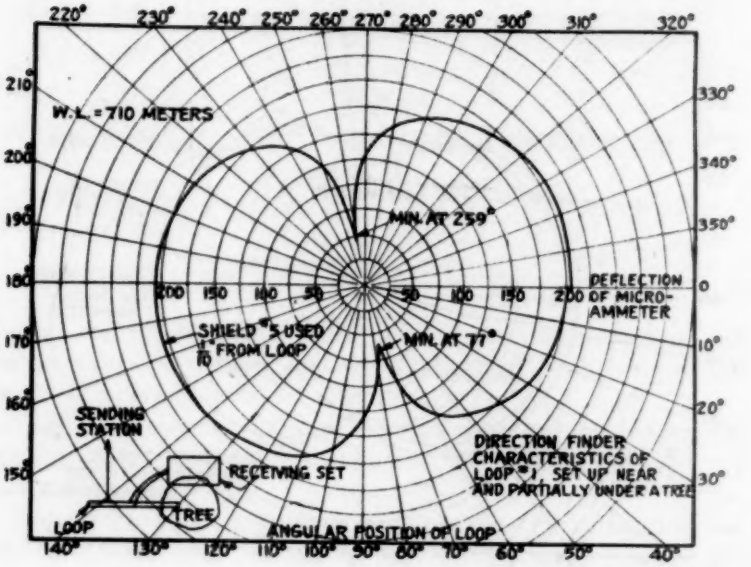
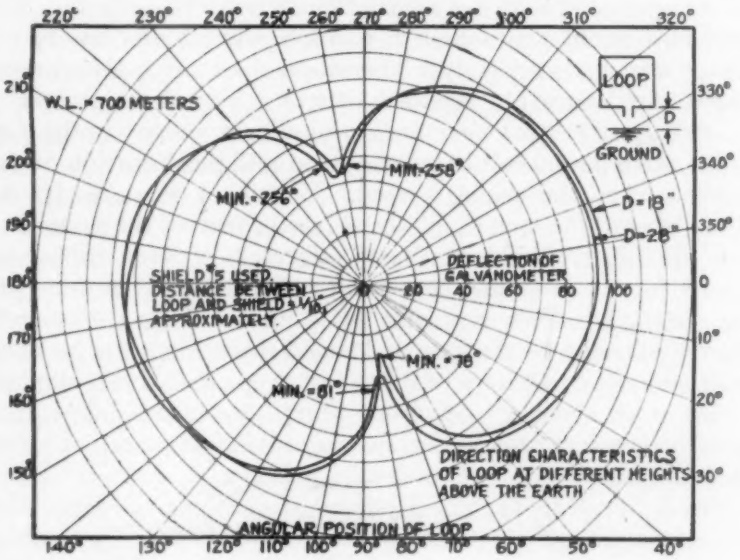

W.L. = 710 METERS
MIN. AT 259°
MIN. AT 77°
DEFLECTION OF MICRO-AMMETER
SHIELD "S" USED 1" FROM LOOP
SENDING STATION
RECEIVING SET
TREE
LOOP
DIRECTION FINDER CHARACTERISTICS OF LOOP "L" SET UP NEAR AND PARTIALLY UNDER A TREE
ANGULAR POSITION OF LOOP

Fig. 68 is a partial record of the effect of changing the distance of the loop above the earth. It is seen that even the relatively small change from a height of 18″ to one of 28″ causes noticeable improvement in symmetry and sharpness of minima. It has been found that still better results may be had at a height of 4 or 5 ft., and when the entire apparatus was placed in a wooden barn 20 ft. from the ground extremely accurate settings could be made.

FIG. 68.



The general conclusions that were derived from all of these experiments with particular reference to the various factors affecting the accuracy (that is, the sharpness and position of the minima) of the direction finder are as follows:

(*a*) *Sharpness and Symmetry of Minima.*—With a single simple loop the minima are sometimes sharp and sometimes very broad and are not generally equal nor 180° apart.

(*b*) *Effect of Electrostatic Shield.*—The use of an electrostatic shield above the loop is in general very advantageous in improving the sharpness and symmetry of the minima. It does not noticeably reduce the strength of received signal.

(*c*) *Pancake vs. Solenoid Loops.*—The minima of the pancake type loop are generally broader than those of the solenoid type. There is a greater difference in the amplitudes of the two oppositely directly maxima for the pancake than for the solenoid.

(*d*) *Grounding Any Part of the Receiving Apparatus.*—Either grounding parts of the receiving apparatus (for example, grounding the filament battery of an amplifier to prevent its "howling") or placing parts of the apparatus close to the earth broadens the minima and therefore decreases the accuracy of the loop (partial grounding of the set through the telephone receivers on the operator's head has a small though noticeable effect). The grounded shield was found to partially correct this loss in accuracy but not completely. Therefore, the receiving apparatus and batteries should be kept at least 2 or 3 feet off the ground.

(*e*) *Proximity of Loop to Earth.*—The proximity of the loop to the earth produces a broadening and a slight distortion of the minima when the shield is used. To obtain good results the lower edge of the loop should be at least 4 feet off the ground.

(*f*) *Effect of Nearby Metal Objects.*—A Ford truck was placed very close to the loop (with a shield) and was found to have negligible effect, even with the frame of the truck grounded. On the other hand, the loop and shield when used in a building with numerous radiators of a heating system in it, gave minima which were about 4° off from being 180° apart. The loop should, therefore, not be set up near extended masses of metal or near wires.

(*g*) *Effect of Trees.*—Scattered trees 30 or 40 feet from the loop have negligible effect on the direction finder. A tree which is but a few feet away causes a slight distortion of the minima. Many large trees 30 or 40 feet from the loop and between the loop and the transmitting station appreciably reduce the strength of signal.

(*h*) *Effect of Atmospherics.*—Certain kinds of atmospherics are considerably reduced by the grounded shield.

(*i*) *Polarity of Loop.*—Under ordinary conditions the solenoidal loop with or without the shield gives one minimum sharper than the other. Reversing the leads from the loop to the receiving set reverses the sharp minimum.

(*j*) *The Distance of the Shield Above the Loop.*—The best distance of the shield above the loop was found to be about ¾" to 1½" for the apparatus of ordinary dimensions.

(*k*) *Use of Shield When the Complete Direction Finding Apparatus is High Off the Ground.*—Although the shield is very effective in sharpening the minimum when the loop is 3 or 4 feet off the ground, and the receiving apparatus 2 or 3 feet off the ground, it loses its value when all the apparatus is 15 or 20 feet from the ground. Under these conditions the loop has good directional qualities without a shield.

III.

PRACTICAL DEVELOPMENTS AND USES.

While it is not essentially the purpose of this report to describe in detail the several practical developments of radio direction finding apparatus that have been made nor its uses, it is, nevertheless, interesting, in connection with the work described above, to mention certain special applications that have been made of the principles involved which are believed to be novel.

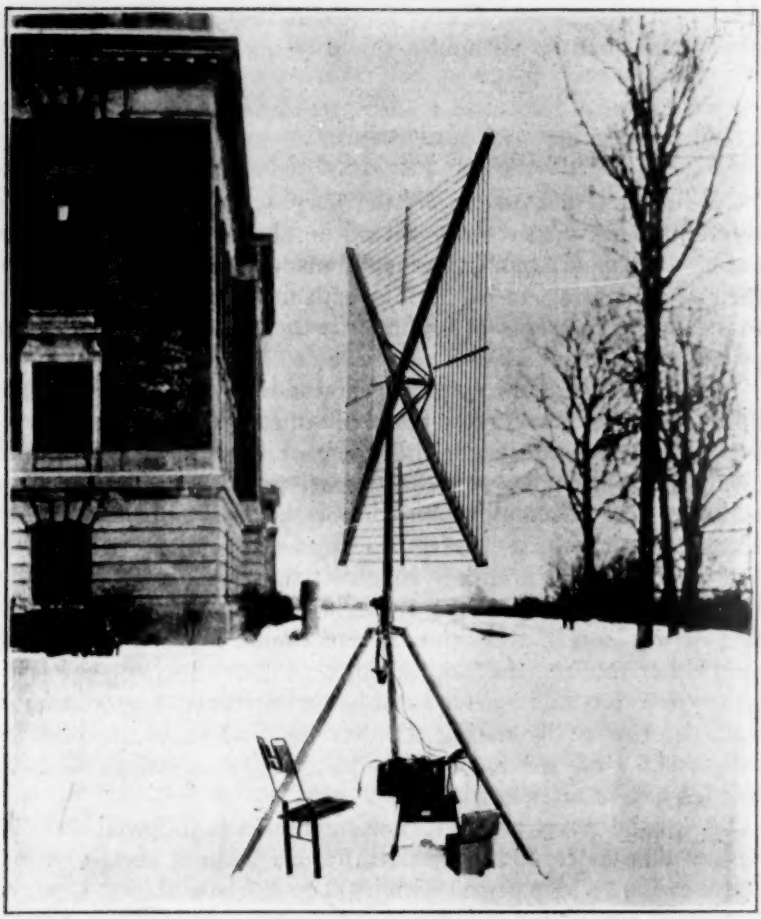
One of these is the construction and use of a single loop for finding *absolute* direction, a result obtained by properly augmenting the antenna effect and the phase of same so as to produce distortion in the polar curve characteristic with unequal maxima and minima. A photograph of a portable field apparatus which accomplishes this in a satisfactory way while retaining sufficiently sharp minima for accuracy in directional settings is shown in Fig. 69. Absolute direction or sense is obtained by a rough setting of the loop in a position for maximum signal strength and then either rotating the loop through 180° or reversing the leads to the detector. The directional sense of the sending station is then determined by noting whether the first or the second arrangement gives the louder signals. The exact line is fixed, as usual, by right angle settings.

A second novel method of using the loop followed the discovery that at certain heights, different from a certain value, above ground a loop placed with its plane horizontal, that is parallel to the earth, acted as a very good receiver and was practically non-directional. Such an arrangement is useful for many purposes, such, for example, as intercept work.

A combination of vertical loop, giving the two-leaved characteristic, with a horizontal loop, giving a circular characteristic, may be used to get absolute direction, and by suitable switching

arrangements the horizontal loop may be used alternately as a shield for improving the sharpness of minimum and for giving antenna effect, as just described, and getting absolute direction.

FIG. 69.



A model has been standardized by the Signal Corps using a carefully designed solenoidal type loop with an electrostatic shield for very accurate direction finding work.

It was found (December, 1917) that when the plane of a loop of certain design was placed at a certain angle with the earth

and at a certain height no radio signals could be received from certain directions. While the uses to which this important discovery have been put cannot be disclosed at the present time, it may be stated that they are concerned with a very great improvement in the reliability of radio communication. Other arrangements of specially constructed loops and associated apparatus have also been developed and are being improved with the same end in view.

In concluding this paper, it should be stated that a great deal of the work that has been done on the loop direction finder itself has been paralleled by investigations and development of multistage amplifiers, necessity for the use of which has been pointed out above. A seven tube amplifier comprising three stages of radio frequency amplification, a detector tube, and then three stages of audio frequency amplification, has been developed and standardized by the Signal Corps for direction finding work. This instrument is more sensitive, has fewer adjustments, is less noisy, lighter and more compact, and altogether a more generally satisfactory instrument in operation than any similar apparatus having the same order of amplification that has been developed by either the British, the French, or the Germans. The total overall power amplification obtained on weak signals is of the order of 10^{14} times. A novel feature of the amplifier is the use of iron in the radio frequency transformers which couple the radio stages. Incident to the development of this and similar amplifiers a very thorough study was made of the characteristics of iron at radio frequencies, and data were collected giving the permeability and losses in steel that was found suitable for use in these transformers. The iron that has been used in this work is 0.0015″ thick, lacquered with a special enamel to the thickness of 0.002″. It is a low carbon steel containing no appreciable amount of silicon.

Using the seven stage amplifier just mentioned and a loop small enough to be easily accommodated in an ordinary size room, it has been possible to receive signals from all of the high power European stations.

The loop has been used for direction finding on both damped and undamped waves. In the latter case, as has been described above, either a separate local heterodyne may be used at the receiver, or the receiving circuits themselves can be made to oscillate. Using a separate heterodyne, care must be taken to prevent

any direct action of the local oscillation on the loop circuit itself, because in such cases the directional setting will be incorrect. This is because the signal produced is due to the combination of the signal wave and the heterodyne wave, and almost any setting can be obtained, depending upon the amplitude of the local wave and upon the direction from which it intercepts the loop. When using a separate heterodyne, the local oscillation must be introduced into the circuits through a small localized coupling with no leakage of the loop system.

Finally, adaptation of the loop receiver has been made to the airplane in another special form of apparatus for direction finding and the same principles and data given above have been applied in the design of the loops for this purpose.

Corrosion in Lenses. (*The British Journal of Photography*, vol. lxvi, No. 3088, p. 389, July 11, 1919.)—If lens users would acquire a little elementary knowledge concerning the nature and properties of glass, their instruments would stand a much better chance of keeping in good condition than they do at present. It should be known that what we call "optical" glass is made in a great variety of qualities, each of which is capable of taking its place in one or other of the many kinds of lenses. Some are as hard and impermeable as the glass we use for windows and tableware, while others are soft enough to be easily scratched or even dented, while injudicious polishing will quickly dim the exquisite surface upon the perfection of which so much depends. This is especially the case in some of the earlier anastigmats in which very soft and easily corroded glasses were used because others were not available. It is perhaps news to many people to learn that some glasses are so susceptible to damp that a single drop of water left upon the surface for a few hours will leave an ineradicable mark, while the presence of a film of condensed moisture will give rise to a general corrosion, which in mild cases shows in prismatic colors like those of a soap-bubble, and in severe ones as a yellow stain accompanied by a distinct depolishing of the surface. Unfortunately, there is no cure for this evil, for even the maker of the lens cannot repolish it to the same accuracy of figure that it originally possessed. Forewarned is forearmed, and knowing what is likely to occur the prudent man does not allow his lenses to stand about exposed to the atmosphere, but keeps them in tightly-closed cases when they are not actually in use. Failing a case, which also protects the brasswork, a well-fitting cap at the back as well as the front is an excellent protection.

THE LOW VISIBILITY PHASE OF PROTECTIVE COLORATION.*

BY

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A CAREFUL analysis of protective coloration as a means of defense against attack by submarines leads to the conclusion that the subject may, from the standpoint of fundamental method, be divided into two quite distinct and different parts. The object to be accomplished is the same in both cases, that is, to prevent the destruction by submarine attack of the protectively colored craft. This object may be attained by either of the two general methods. The first, which will be called "low visibility" coloration, involves the application of paint (together with certain structural modifications that may be necessary), in such a way that the craft treated so nearly matches the background against which it must be viewed as to be invisible or less visible to an observer on the submarine. The second, which will be called "deceptive" coloration, involves the application of paint or the modification of structural details, or both, in such a way as to deceive the submarine's observer in his estimate of the nature of the craft, her range, course or speed, thus preventing the submarine from ever reaching an advantageous firing position, or, in case it is reached, to so confuse the submarine's commander in his calculations that the torpedo will not be discharged in such a direction as to secure an effective hit. This latter method aims not at preventing an attack from being made, but at preventing the attack from being successful.

It is quite evident that the first method will be most effective when the distance between the submarine and the protectively colored craft is relatively great, let us say, in excess of 5000 yards. Likewise, it is reasonable to conclude that the second method will be found most effective at relatively close range, under 5000 yards. This conclusion follows from consideration of the fact that "deceptive" coloration depends for the efficiency of its operation

* Communicated by Dr. C. E. K. Mees. Communication No. 80 from the Research Laboratory of the Eastman Kodak Company.

upon the visibility of the shape and color of various contrasting areas produced by the application of paint alone or in conjunction with certain modifications of structural details. Since "low visibility" coloration and "deceptive" coloration differ in the means employed for the accomplishment of the desired result, it will be necessary to treat each separately.

When the work on this subject was taken up a survey of the field showed that at that time no method for the numerical specification of visibility, or instrument for its quantitative measurement, was available. The first step, therefore, was the working out, from the theoretical standpoint, of the fundamental laws upon which the quantitative evaluation of visibility could be based. Following this an instrument, operating upon the proper principle as indicated by the theoretical equations, and suitable either for the measurement of visibility values of small models under known conditions of illumination and background or of actual boats at sea, was designed and built. This having been accomplished, it remained to apply the method and instrument to the determination of the best color for low visibility under any specified weather condition.

In this paper it is proposed to present some of the data resulting from the application of the method and instrument to the measurement of visibility. Since the theory of visibility and of the instrument constructed for its measurement have been treated in detail in a previous paper,[1] those phases of the subject will be only briefly considered at this time, thus permitting the placing of greater emphasis upon the practical results obtained. It will be necessary, however, in order to understand the data and their interpretation, to consider briefly the fundamental laws governing the visibility of objects and the method adopted for the numerical specification of its value.

In general, it may be said that non-luminous objects are visible by virtue of the light reflected from them. However, any particular object in the field of vision becomes visible as such only by contrast with its surroundings—that is, when the light emanating from that object (either by reflection or emission) differs in some respect from the light flux which enters the eye from the projected space immediately surrounding that object. The sensation caused by the incidence of radiant energy, which we call

[1] Paper read at meeting of American Physical Society, April, 1919.

light, upon the retina of the eye may be said to consist of two factors, brightness and color, the former being dependent upon the intensity and the latter upon the quality of the incident radiation. This second factor of the sensation may also be said to consist of two parts, hue and purity or saturation. Hue refers to the position, in the spectrum, of the dominant wave length, and saturation expresses the proximity of the color to monochromatism. It is evident, therefore, that a sensation due to the impingement of radiant energy upon the retina may vary in three respects, that is, with respect to brightness, hue, and saturation. A contrast in the visual field resulting in the visibility of an object may be due, therefore, to brightness contrast, to hue contrast, or to saturation contrast; or to a combination of any two or of all three of these factors.

NOMENCLATURE AND DEFINITIONS.

The intensity factor of the sensation resulting from the incidence of radiant energy upon the retina is expressed in terms of brightness. The brightness, B, of an element of luminous surface from any point of view may be expressed in terms of the luminous intensity per unit area of that surface projected on a plane perpendicular to the line of sight. When expressed in this manner it is measured in candles per unit area of the projected area. Brightness may be expressed also, and perhaps more logically, in terms of the specific luminous radiation of an ideal perfectly diffusing surface, that is, a surface obeying Lambert's law. The brightness unit in this case is the Lambert which is defined as equal to the brightness of an ideal surface radiating or reflecting one lumen per square centimetre. In practice, this unit is too large for convenience and hence the millilambert of .001 lambert is used. An ideal, perfectly diffusing surface emitting one lumen per square foot will have a brightness of 1.076 millilamberts. Measurements of brightness are made by means of a suitable form of photometre calibrated to read directly in the desired brightness units. The brightness of a surface depends upon two factors, the illumination of that surface and its reflecting power.

The illumination, E, of a surface at any point is the luminous flux density on the surface at that point, or the flux per unit of intercepting area. "Luminous flux," F, is the rate of flow of radiant energy evaluated with reference to the visual sensation.

and is expressed in lumens, the lumen being defined as equal to the flux emitted in a unit solid angle (steradian) by a point source of unit candle power. The *c. g. s.* unit of illumination is the phot, which is defined as one lumen per square centimetre. The practical unit in most common use, however, is the foot candle which is defined as one lumen per square foot, and which is equal to 1/076 milliphots. For a uniformly illuminated surface,

$$E = \frac{F}{S},$$ S being the area.

Illumination is measured by a special type of photometer, usually referred to as a lumeter or illummometer, this being calibrated to read directly in some suitable illumination units.

The coefficient of reflection or total reflecting power of a surface is defined as the ratio of the total reflected luminous flux to the total incident luminous flux. In most practical work this value is not of great importance, the value desired being that of the reflecting power of the surface measured under certain specified conditions, such as the angle of incidence of the flux and the position from which the surface is viewed. The term "reflection factor," R, is used to indicate this particular value and is defined as the ratio of the reflected to the incident flux. Reflection from a surface may be either specular, diffuse, or a mixture of the two. In the case of pure specular reflection all of the incident flux is reflected in such a way that the angle of reflection is equal to the angle of incidence; while in the case of completely diffuse reflection the reflected flux is equal in all directions, regardless of the angle of incidence, the distribution being in accord with Lambert's cosine law. Very few cases of pure specular or diffuse reflection are found in practice, there being generally a superposition of the two. The reflection factor is measured by the use of the reflectometer, a photometer of special design, care being taken that conditions of illumination and angle of view are such as to give correct values for application in the particular case under consideration. This value is purely numeric and is usually expressed as a percentage value. If, with a specified condition of illumination, the reflection factor, R, and the brightness, B, of the surface are measured from the same position, then $B = E \cdot R$, and hence the value of E may be determined; or in any case where two of these factors are known the third can be computed.

The quality factor of the luminous flux is that property which depends upon the spectral distribution of that flux, color being

defined as the subjective evaluation as expressed in terms of hue and purity or saturation. Hue is that property of color which depends upon the variation in the sensation due to the variation of the wave length of the luminous flux, while saturation expresses the proximity of the color to a condition of monochromatism. Monochromatic spectral light has a saturation of 100 per cent., while pure white light has a saturation of zero. White, therefore, is a limiting color, having no hue and zero saturation. In practice it has been found convenient in many cases to express the saturation factor in the inverse order, that is, as impurity rather than purity. The term used in such expression is called the "per cent. white," for which the symbol I is used. Thus a color for which $I = 100$ per cent. is equivalent to zero saturation, and if $I = 0$ per cent., saturation is 100 per cent.

It has been demonstrated experimentally that any color can be matched by the mixture, in the proper proportions, of white light with monochromatic spectral light of the proper wave length. In this way a direct measurement of the fundamental sensation properties of a color may be made. The hue is specified by the wave length of a monochromatic light used (wave length of the dominant hue). The saturation is specified either as the purity (per cent. hue) or as the impurity (per cent. white), the former value being obtained from the ratio of the intensity of the monochromatic to the total intensity (monochromatic plus white) of the mixture, while the latter value (per cent. white) is given by the ratio of the intensity of the white to the total intensity of the mixture. These values are pure numerics. The usual unit used in expressing the wave length of light is the millimicron, which is equal to .0000001 centimetre and is designated by the symbol $\mu\mu$.

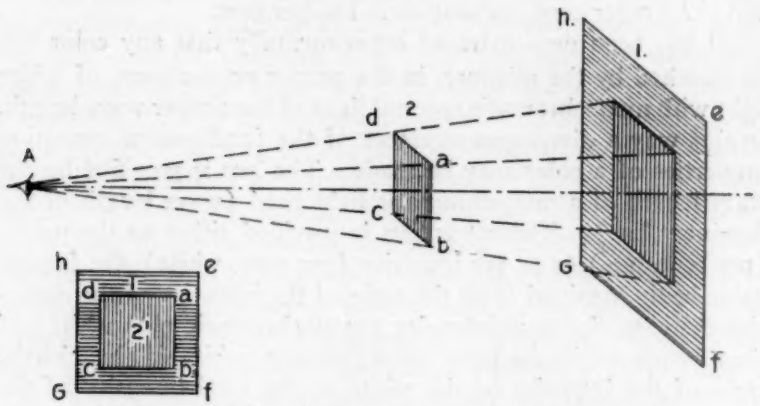
In the foregoing paragraphs have been defined the various terms that will be used in the following discussion of the subject of visibility. These are summarized briefly in the following table for convenience of reference:

Symbol.	Quantity.	Unit.
F	Luminous Flux	Lumen
E	Illumination	Foot Candle
B	Brightness	Lambert
R	Reflection Factor	Per cent.
H	Hue	Wave length ($\mu\mu$)
S	Saturation	
	Purity	Per cent. Hue
	Impurity	Per cent. White

THEORETICAL ANALYSIS OF THE LOW VISIBILITY PROBLEM.

For the purposes of the theoretical treatment of this problem it will be necessary to make certain simplifying hypotheses. Begin first with the problem of the determination of the visibility of an object uniform in color and brightness viewed against a background also of uniform color and brightness. In Fig. 1 this case is shown in perspective, 1 being the background, 2 the object, and A the eye or viewpoint. The visual field will appear as shown in the lower left hand drawing of Fig. 1, 2 representing the object (rectangle *abcd*) and 1, the background (rectangle *efgh*).

FIG. 1.



A diagrammatic illustration of the relation of object to background.

The terms used in the discussion and the symbols employed are as indicated previously, except that a subscript number or letter attached to a given symbol indicates that the term applies to the object or surface designated by that number or letter. Thus E_1 is the symbol used for the illumination on the surface 1, the background.

Assume for the moment that the object and background are illuminated by light of the same quality and also that this quality be specified as white, which is defined as light from the noon sun on a clear day or its spectral equivalent. Now, the visibility, V, of the object as seen against this background is dependent upon the total contrast existing between the two. This total contrast

is made up of the three factors: (1) Brightness contrast, C_b; (2) Hue contrast, C_h, and (3) Saturation contrast, C_s. These three factors of the total contrast may be evaluated as follows:

$$C_b = f(B_1, B_2)$$
$$C_h = f(H_1, H_2)$$
$$C_s = f(S_1, S_2)$$

The total visibility may then be expressed in the general form,

$$V = f(C_b, C_h, C_s).$$

The laws governing the reaction of the retina to the various brightness stimuli are so well established that it is comparatively easy to evaluate the term $C_b = f(B_1, B_2)$ directly in terms of visibility, to make quantitative measurements of visibility as such, and to correlate such determinations made under widely different conditions. Unfortunately, the other terms, C_h and C_s, cannot be so readily evaluated. This is due to the lack of knowledge concerning the fundamental reactions of the retina to these stimuli. However, it is possible by a direct method of measurement to determine the total visibility of an object against a given background. Such a value includes in a single term the visibility due to all three kinds of contrast. Since the part of total visibility due to brightness contrast may be determined independently, a means is thus available of evaluating that part of visibility due to the combined effect of hue and saturation contrast. Since hue and saturation are the two factors of quality, the part of total visibility due to hue and saturation may for convenience be designated as quality contrast, C_q. It should be borne in mind, however, that this term includes two independent variables, both of which must be considered in any evaluation of visibility due to quality contrast. It is entirely possible that the visibility due to C_h and C_s could be evaluated separately, but this would require a large amount of fundamental research, which it will not be advisable or necessary to go into at this time.

The visibility resulting from brightness contrast is directly proportional to the subjective contrast and hence, for an eye adapted to a fixed brightness level, to the ratio of the two brightnesses B_1 and B_2. Therefore, we may write:

$$V_b = \int \left(\frac{B_1}{B_2}\right) \qquad (1)$$

Now, suppose that to both B_1 and B_2 some brightness, B_v, is added and that B_v is of such magnitude relative to B_1 and B_2 that,

$$\frac{B_1 + B_v}{B_2 + B_v} = k \tag{2}$$

Where,

$$k = 1 + \triangle \frac{B}{B_1} \tag{3}$$

$\triangle B$ is the least perceptible difference in brightness when the eye is adapted to a field brightness of B_1.

The superposed brightness, B_v, will be referred to as "veiling glare," and the magnitude of B_v required to satisfy the equation above may be taken as a direct measure of the visibility of an object under fixed conditions. It is evident, however, that the value of B_v required by the equation will depend not only upon the ratio of B_1 to B_2 but also upon the absolute values of those terms. An evaluation of visibility dependent upon the ratio of B_1 to B_2 and independent of their magnitude may be obtained by writing

$$V_b = \frac{B_v}{B_1} \tag{4}$$

It is evident that a variation in value of any one of the four terms, E_1, E_2, R_1 and R_2, will cause a corresponding change in the value of V_b. Visibility may be evaluated, therefore, as a function of any one of these four terms as a variable and the remaining three as constants. It is entirely possible to evaluate each of these functions, but a consideration of the problem to which the theory is later to be applied shows that this is not necessary and that a different method of evaluation is more directly applicable.

As will be shown later, the sky forms the background in most of the cases to be considered, and it is impossible in general to treat the sky as a surface. It is not possible, nor is it necessary, to determine independently the values of the reflection factor and illumination in dealing with this sky background. However, its brightness can be measured easily, and from the standpoint of brightness the sky may therefore be regarded and treated as a surface. The variables E_1 and R_1 are therefore eliminated from this problem, being replaced by a single term, B_1. This leaves for consideration the three variables, E_2, R_2 and B_1, for each of which as a variable an evaluation of V_b may be formulated. Again,

considering conditions in nature, it will be seen that E_2 and B_1 are not in general independent variables but more or less dependent one upon the other. It is desirable, therefore, to combine these two into a single term, as a function of which visibility may be expressed. This combination of B_1 and E_2 is best accomplished by taking the ratio of the former to the latter. This ratio is a complete specification of the lighting conditions at any instant, and is therefore in the practical problem of an object illuminated by natural light a complete specification of the weather conditions at a given time. This term will be referred to as the "weather coefficient," W, its evaluation in terms of the other quantities being expressed by the equation,

$$W = \frac{B_1}{E_2} \tag{5}$$

The variables to be considered are, therefore, R_2 and W, and the necessary evaluations of visibility are of the form, $V_b = f(R_2)$, W = a constant; and $V_b = f(W)$, R_2 = a constant. The first equation when properly formulated will make possible the computation of the variation in visibility due to a variation in the value of the reflection factor, for any specified value of the weather coefficient; the second equation will give the variation in visibility with the value of the weather coefficient for any object of definite reflection power.

Before proceeding with the formulation of these visibility functions it is desirable, for the sake of clearness, to summarize briefly the terms thus far defined which must be used in the subsequent development of the theory.

B_1 = Brightness of background.
R_2 = Reflection of factor of object.
E_2 = Illumination of object.
R_2 = Reflection of factor of object.
B_v = Brightness of veiling glare which when superposed over object and background will reduce the contrast to a just imperceptible value.
V_b = Brightness visibility.
W = Weather coefficient.
k = Contrast of the eye.

The evaluation of visibility due to brightness contrast in terms of W and R_2 leads to the following general expression:

$$V_b = \left(\frac{1}{W} \cdot R_2 \cdot \frac{c}{1-c}\right) - \frac{1}{1-c} \tag{6}$$

Where c is a constant depending for its value upon whether B_1 is greater or less than B_2.

If,

$$\frac{B_1}{B_2} > k, \qquad c = k$$

or if,

$$\frac{B_1}{B_2} < k, \qquad c = \frac{1}{k}$$

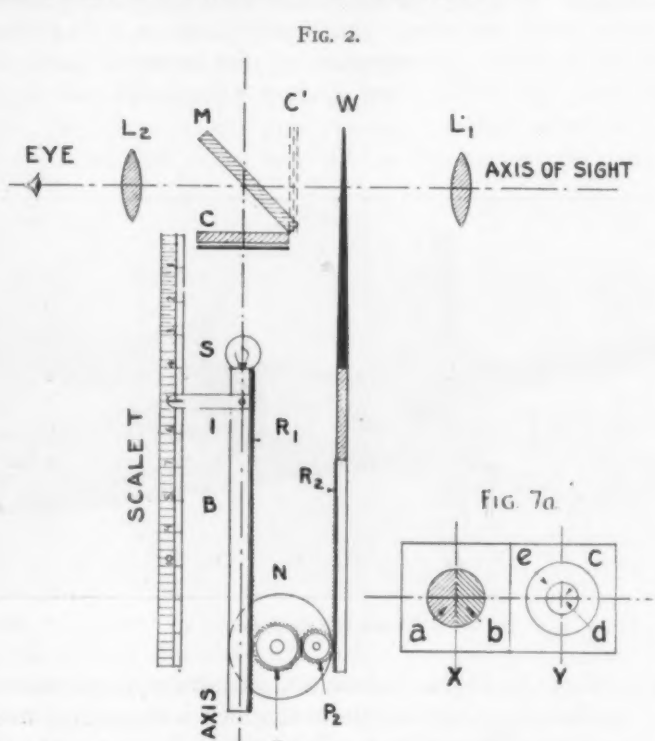
It will be noted from the form of the expression that visibility as a function of W (R_2 = a constant) will be represented by a rectangular hyperbola and as a function of R_2 (W = a constant) by a straight line.

THE VISIBILITY METRE.

The general principles upon which the specifications of visibility must be based have been outlined in the section dealing with the theory of the subject. It will be remembered that visibility may be specified in terms of the brightness of a veiling glare, B_v, and the brightness of the background, B_1, against which the object is viewed. This veiling glare was defined as that brightness which, when superposed upon the visual field composed of an object and its background, will reduce the apparent contrast between object and background to the limit of visibility. It will be remembered that the discussion referred to dealt with the evaluation of the visibility due to brightness contrast, V_b. Now suppose that in addition to a brightness contrast, a contrast in either hue or saturation also exists. The amount of veiling glare required to reduce the total contrast to a just perceptible value will in general be greater than in case the color contrast was not present. It is entirely logical, therefore, to apply the same general method for the evaluation of total visibility, that is, the superposition over the object and background of a veiling glare of sufficient brightness to reduce the total contrast to zero. The distinction between the terms V_b and V, the total visibility, should, however, be borne in mind. The total visibility in any case, whether that visibility be due either to brightness, hue or saturation contrast, or to any combination of these terms, is evaluated in terms of the equivalent brightness contrast which would produce the same degree of visibility. The validity of such a method is strongly supported by the fact that loss of visibility in nature is almost entirely due to the presence of a veiling glare which is quite con-

stant in quality, its color being approximately white, but variable in intensity. This natural veiling glare arising from the presence of diffusing material in the foreground space produces a lowering of the visibility value regardless of whether the initial visibility is due to brightness, hue or saturation contrast.

FIG. 2.

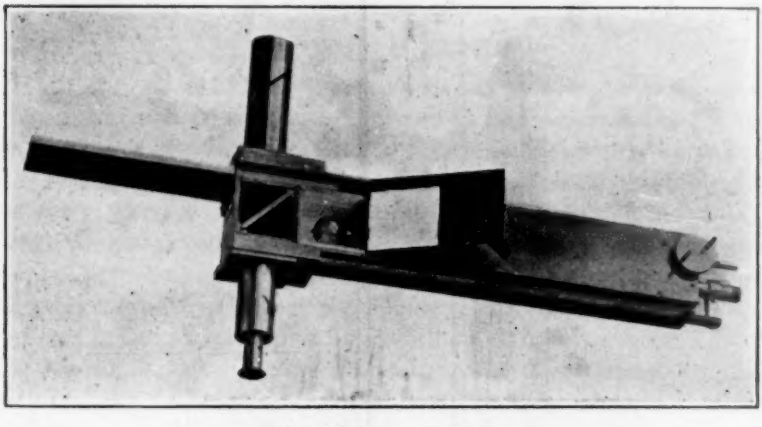


Diagrammatical illustration of the visibility metre.

It was necessary to design and build an instrument and to develop methods for the precise measurement of the quantities, B_v and B_1, under practical conditions. After extensive preliminary trials a satisfactory instrument was developed. Several different types, all operating upon the same basic principles, hav-

ing been designed, the type which appeared to be most convenient for practical work was chosen and a complete instrument constructed. This instrument is called a "visibility-metre" and patents covering the basic principles upon which it is constructed and several particular designs have been applied for by the Eastman Kodak Company, in whose Research Laboratory these experiments were conducted. In Fig. 2 is given a diagrammatic sketch showing the arrangement of the essential parts of the instrument, and Figs. 3 and 4 show photographs of the completed instrument.

FIG. 3.

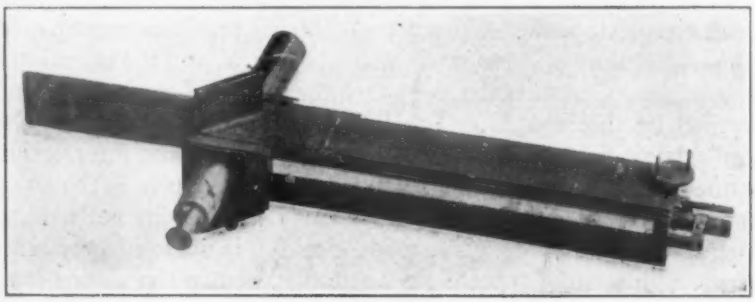


The visibility metre open.

The letter *M*, Fig. 2, indicates a semi-transparent mirror set at 45° to the axis of the instrument, which is coincident with the axis of sight. This mirror reflects about 60 per cent. of the incident light and transmits approximately 20 per cent., the remaining 20 per cent. being absorbed. The secondary axis of the instrument is a line perpendicular to the axis of sight at the point where the reflecting surface intersects the axis of sight. *C* is a diffusing member composed of pot or flashed opal glass placed perpendicular to the secondary axis. This diffusing surface is illuminated by a light source, *S*, mounted so as to move along the secondary axis. This source is mounted at one end of a brass tube, *B*, on one side of which is the rack, R_1. A knurled hand wheel, *N*, is mounted rigidly on a shaft carrying also the pinion,

P_1, which engages the rack, R_1, thus providing for the movement of the source along the secondary axis by a rotation of the hand wheel, N. A second pinion, P_2, in mesh with P_1, engages the rack, R_2, which is rigidly attached to the frame carrying the neutral gray non-diffusing optical wedge, W. This wedge varies continually in opacity from one end to the other, and is so arranged as to move across the axis of sight. The object lens, L_1, is of such focal length that the object of which the visibility is to be measured is imaged sharply at the point where the reflecting surface, M, intersects the axis of sight. This lens is adjustable in position, so that either near or far objects may be imaged in

FIG. 4.



The visibility-metre closed.

the proper plane. The eye lens, L_2, is of such power that the magnification of the system is unity, thus giving a retinal image of the same size as when the object is viewed with the naked eye. The lens L_2 enables the eye to see clearly defined the image formed by the lens L_1. The mirror M may be replaced by a simple photometric field for the purpose of measuring brightness, it being necessary to measure B_1 in order to obtain the visibility value. The details of the interchangeable field are shown in the small right-hand drawing of Fig. 2.

In order to increase the sensibility of the instrument in the measurement of B_v, a strip of clear gelatine film is placed over one-half of the field, thus increasing the reflecting power of that half by about 8 per cent. If a be the half of the field thus covered, it will for a given position of the source, S, cause a brighter veiling glare to appear as superposed over the object and back-

ground than the other half of the field, *b*. Now, if the object be so adjusted in the field of the instrument that the line between the two halves of the field bisects (approximately) the object, that part of the object in the field *b* will still be visible when the other part (that in field *a*) has been completely obscured by the veiling glare of that part of the field. In this way certain limits are set between which every setting must be made. If it is desired to decrease the difference in brightness between the two parts of the field (in order to narrow the limits of the setting), this may be done by making the reflecting powers of one-half of the field any desired amount greater than the other. This is easily accomplished if the reflecting surface is made by depositing the reflecting metal on the glass by a cathodic discharge.

The photometric field is made by covering one-half, *c*, of the small circular opening with a piece of highly reflecting matt paper. The white paper is illuminated by the source, *S*, and the other half, *d*, being open, permits the eye to see the image of the background formed by the lens L_1. The line between *c* and *d* (when the photometric field is in a position for use) lies at the intersection of the axis of sight with the secondary axis and hence in the plane in which the object is imaged by the lens L_1. The circular field, *e*, surrounding the photometric fields, *c* and *d*, is made of grey matt paper. This is the type of field actually used in the instrument, but any of the well-known types, such as a Lummer-Brodhum cube, may be substituted if desired, the chief requirement being a sharp dividing line lying in the image plane. These two fields are mounted in a small metal frame, sliding in milled metal ways placed perpendicular to the plane through the axis of the instrument. Stops are provided so that each field may easily and quickly be brought into position with the axis of sight passing through the centre of the field being used. A light filter is placed at *F*. This filter is of such quality that the light from the source *S*, after passing through the filter, matches in color the light which illuminates the object and background. A graduated scale, *T*, is fastened rigidly to the case which incloses the source. An index, *I*, attached to the source or its supporting member moves along this scale, indicating at all times the position of the source, *S*, and wedge, *W*, with reference to the axis of sight. The scale is so calibrated that from the position of the index at any instant the brightness of the glare field, B'_v, and the opacity of the wedge on

the axis of sight can be determined. By turning the hand wheel N, the source, S, and the wedge, W, are caused to move simultaneously and in such fashion that an increase in the brightness of the veiling glare, B_1, is accompanied by an increase in the opacity of the wedge on the axis of sight. This increase in opacity causes a diminution in the intensity of the light which reaches the eye from the object and background.

Now the light transmitted by the diffusing member, C, is reflected into the eye, appearing to come from the image of that surface. Thus diffuse white light is caused to enter the eye from a point between the eye and the object being observed, increasing the apparent brightness of both object and background by the same amount and causing the ratio of B_1 to B_2 to be lowered. At the same time the wedge, W, is introduced, causing a proportionate reduction in the apparent brightness of B_1 and B_2.

It will be seen, therefore, that the action of the instrument is exactly analogous to the action of material particles distributed throughout the foreground space, *i.e.*, the production of a veiling glare between the eye and the object and the absorption of a certain percentage of the light reflected or emitted by the object and background. Now, if the source and wedge be moved to such a position that the object is just visible in one part of the field and not visible in the other, a setting is obtained from which the values of B'_v and D_0 can be determined.

In our fundamental equations, B_v was defined as the brightness of the veiling glare which when superposed over object and background will reduce the visibility to zero or a just perceptible value. It will be noted that as no term covering the decrease in brightness due to absorption of light in the foreground space appears in those equations, it is inferred that the entire loss of visibility is produced by the veiling glare, B_v. Now the effect of the introduction of an absorbing member, such as the wedge W, is merely to decrease the amount of veiling glare required to reduce the visibility to zero. It is not feasible in practice to produce the extinction of visibility by a veiling glare alone, due to the fact that the values of B_1 and B_2 are so high that a source of very high intensity would be required to give the required value of B_v. As it is desirable to make the instrument as portable as possible, such sources cannot conveniently be used on account of the excessive weight of storage batteries required to operate them. By using

an absorbing wedge in the axis of sight a much smaller lamp may be used. Such procedure does not in any way interfere with the correct determination of B_v. In order to obtain the maximum possible illumination on the diffusing member with a lamp to given energy consumption, the interior walls of the chamber inclosing the source, S_v, are painted white. This tends to increase the brightness of the diffusing member and also to increase the uniformity of illumination on this surface, which is extremely desirable. This painting of the interior walls prevents the use of the inverse square law in computing the illumination on the diffusing surface from known values of intensity of source and distance between source and surface. This, however, does not interfere in any way with the operation of the instrument.

For a given ratio of B_1 to B_2 the value of B_v required to produce a loss of visibility is directly proportional to the absolute values of B_1 and B_2. Thus by reducing the apparent brightness of B_1 and B_2 to one-tenth of their actual value by means of the member W, only one-tenth of the amount of veiling glare from the surface of M will be required to produce a given lowering of visibility. The brightness of the glare field of the instrument will be designated by B^1_v and should not be confused with the term B_v appearing in the equations. The value of B_v is computed from those of B^1_v and D_a (the density) or T_a (the transmission) of the wedge W at the point through which passes the axis of sight.

The statement that the value of B_v, appearing in the fundamental equations, is directly proportional to B_1 or B_2 and hence inversely proportional to T_a rests upon a basic assumption which should be mentioned at this point. In order for this to be true, k, the contrast factor of the eye, must remain constant. That is, the total field of brightness to which the eye is subjected must not change sufficiently to cause an accompanying change in k. This factor is satisfied in the instrument by so adjusting the density gradient of the wedge W and the linear velocity of the wedge relative to that of the source, that the total field of brightness, B_t, of the instrument remains sensibly constant regardless of the position of the members relative to the axis of sight. It is not possible to obtain exact constancy of B_t for all values of B_1, but B_t can be kept within the range for which k is constant. However, in case B_t should vary beyond the specified range of values, it is

still possible to compute B_v, provided the resulting change in the value of k is known. If B_t is measured, which can easily be done, the corresponding values of k may be obtained. In practice it is found that B_t can be kept within the required limits in almost all cases by choosing a wedge of proper density gradient and by adjusting the number of teeth on the pinions so that the desired relative motions of S and W are obtained.

The above consideration shows that it is not necessary to exactly simulate in the instrument the relations existing in nature between the values of the veiling glare brightness and the opacity arising from the particles suspended in the foreground space. Since this relation is not constant for all natural conditions, being dependent upon the nature, size and spatial distribution of such scattering and absorbing particles, it would be quite impossible to make a single instrument exactly simulating all possible conditions resulting in lowered visibility.

Now it will be noted by referring to the theoretical treatment that

$$V = \frac{B_1}{B_v}.$$

It is necessary, therefore, to determine the value of B_1. This is done by substituting for the glare field, X, in Fig. 2, the photometric field, Y. The instrument being calibrated as a brightness photometer, the value of B_1 is read directly from the scale when a photometric balance exists between the fields c and d. The field d is filled by the image of the background.

In order to obtain a value of W, the weather coefficient, which is defined by the expression,

$$W = \frac{B_1}{E_2},$$

it is necessary also to determine the value of E_2, the illumination on the object plane. This may be done by measurement of the brightness, B_o, of a surface in the object plane of which the reflection factor, R_o, is known. Such a surface is termed a test plane and is made by covering a frame of the proper size with canvas or sail cloth painted with several coats of a matt white paint. The reflection factor, R_o, of this surface is carefully determined by suitable laboratory methods. When determinations of visibility are to be made, this test plane is fixed in the object plane so that its

brightness may be read from the designated point of observation.

The procedure in taking a complete visibility reading then consists of three steps:

(1) With the glare field in position the instrument is so set that the image of the object occupies a position in the field X, Fig. 2, such that the dividing line between a and b approximately bisects the image. The hand wheel N is then turned until the object is just visible in field b, and is invisible in field a. The position of the index on the scale S is then read, giving the scale reading S_1.

(2) The photometric field is thrown into position and the instrument so aligned that the image of the background fills the portion d of the field Y, Fig. 2. N is then turned until d and c are equal in brightness and the position of the index being read gives the scale reading S_2.

(3) The alignment of the instrument is changed so that the image of the test plane fills the field d and a photometric balance is again made by turning N. The position of the index now gives the third scale reading S_3.

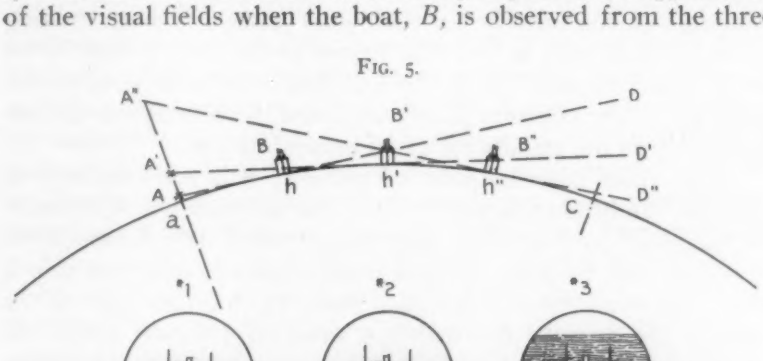
THE VISIBILITY OF SURFACE CRAFT FROM A SUBMARINE.

The treatment of the subject of the visibility of an object thus far has been based upon certain simplifying hypotheses, the chief of which are: (a) an object uniform in color and brightness; (b) a background also uniform in color and brightness. Let us now analyze the problem of the visibility of a ship observed from a submarine and determine how nearly this practical case approaches to the ideal case based upon the stated hypotheses.

First let us consider the background against which the ship must be viewed. In the general case of a ship at sea the background may be composed either of sky or water or some combination of the two. The ratio of the sky to sea in any case depends upon three factors. In Fig. 5 let the line $ah'c$ represent the surface of the sea, A, the point of observation, and B, an elevation of the ship observed. The factors governing the proportion of sky and sea composing the background in any case are: (1) the distance x, represented by the line Aa, the height of the point of observation above the sea level; (2) the distance y, the line AB representing the distance between the point of observation A and the ship observed, B; (3) the height of the observed ship, which

we will call z. The magnitude of x determines the distance between the point of observation and the horizon line, which may be defined as the line which is the locus of the points of tangency between the spherical surface formed by the surface of the sea and all lines passing through the point of observation and tangent to this spherical surface. The positions of the horizon lines for the three observation points, A, A' and A'', are represented in Fig. 5 by the points h, h' and h'', respectively. Let the distance from the horizon line to the point of observation be indicated by the symbol H. The small inserts, 1, 2 and 3, represent the appearance of the visual fields when the boat, B, is observed from the three

FIG. 5.



The ratio of sky to sea in the field of the periscope.

points A, A' and A''. In 1 it will be seen that the entire background against which the boat is seen is sky. This is the case where $y = H$. In 2, part of the background is sky and part sea. Here $y < H$. In 3, the entire background is sea. Here also $y < H$. It will be seen, therefore, if y is equal to or greater than H that the entire background will be sky. These figures are presented merely for the purpose of illustration, numerical data being presented in another part of this report from which the actual proportions of sea and sky composing the background for any specified values of x, y and z may be computed.

Study of the conditions of observation from a hostile submarine preparing to attack a vessel reveals the fact that in practically all cases y is greater than H. When a submarine is operating on the surface, the distance, x, may be as great as 25 feet,

thus giving an approximate value of $H = 12{,}000$ yards. But since the submarine itself must avoid being seen by an observer on the boat to be attacked, this elevation of observation point is only available when the distance, y, is great. When running awash, the value of x is approximately 10, giving a value of $H = 9000$ yards. When submerged, the value of x is seldom over 1 to 2 feet, giving values of H from 4000 to 4500 yards. Thus, in order for the surface craft to be seen against anything but a background composed entirely of sky when observed from the submerged submarine, the distance, y, must be less than 4000 yards; when running awash it must be less than 9000 yards, and when running on the surface must be less than 12,000 yards. It is evident from these considerations that the background to be dealt with in this problem of low visibility is sky only, and hence uniform as considered from the standpoint of its general nature.

Now from the standpoint of visibility it is not necessary to consider the brightness and color of the sky as a whole but only of that small portion which appears to immediately surround the observed ship, forming the background against which the ship is seen. Given an observed boat 400 feet long, 100 feet high (to the tops of the masts), and with the value of $y = 4000$ yards, the visual angle subtended at the eye in the horizontal plane will be approximately $2°$, and in the vertical plane $30'$. The portion of the sky, therefore, which must be considered as the background of any instant is only slightly larger than this, subtending at the eye a vertical angle of $45'$, and a horizontal angle of $3°$. We are concerned with the brightness and color of this field, or, in case the values of these factors are not constant, for all points within this area, with the nature of the variation of brightness and color occurring within the specified area. If this area is uniform in brightness and color, then for low visibility the ship as observed from the specified point of observation should appear of the same color and brightness, uniform over the entire visible surfaces. If the area of sky being considered is not uniform in brightness and color, then the ship, in order to have low visibility, should be so painted that, as viewed from the specified point, the same general variation in color and brightness occurs on the visible surfaces as occurs on the sky background. For instance, if the background appears to be striped in the vertical direction due to alternately high and low values of B_1, then the ship should

appear with perpendicular stripes alternately light and dark. However, extended observation shows that considering a portion of the sky, the lower boundary line of which is the horizon, subtending a vertical angle at the eye of 45′, practically no variation in either color or brightness exists within such a relatively small area. The background, therefore, is in almost all cases uniform, and hence conforms with the assumptions made in the theoretical treatment.

Now let us consider the appearance of the ship. Here both vertical and horizontal surfaces distributed in three dimensions must be considered. Due to the nature of such structures some surfaces receive much greater incident illumination than others. Hence, if all of these visible surfaces are painted with a perfectly matt paint of fixed composition, thus causing all surfaces to have the same reflecting power, with the diffuse conditions of lighting such as occur on dull, overcast days, a great variation in the brightness of the various surfaces may exist. Considering further the fact that all painted surfaces reflect some light specularly and that conditions of more or less direct illumination (such as occur with the sun not at all or only partially obscured by clouds) must be taken into account—it is evident that the existence of regions on the ship of pronounced high light and shadow will exist.

It is clear, then, that our original hypothesis of an object uniform in brightness and color does not apply to the practical case. The failure of this assumption to hold does not in any way invalidate our methods of measuring the visibility even when applied to cases where the object is not uniform in brightness and color. In case the visibility of an object in a given case is due to this lack of uniformity the magnitude of its visibility may still be evaluated by the veiling glare required to produce a disappearance of that lack of uniformity.

In attempting to obtain low visibility by application of paint to the ship the question of highlights and shadows should receive careful consideration and effort should be made to eliminate them as completely as is possible, thus producing an object approximately uniform in brightness and color when viewed from the specified point of observation. The details of working out such a scheme vary with the peculiar nature of the structure under consideration. General laws can, however, be outlined. All surfaces which by nature of their position receive excessive illumina-

tion or reflect excessively in the direction from which observation is to be made should be painted so as to have a lower reflecting power than other surfaces. All specular reflection should be reduced to a minimum by the use of matt paints. Surfaces which by virtue of their position receive less illumination than the average should be raised in reflecting power by the use of lighter paints. Shadows may also be lightened by increasing the incident illumination. In some cases this may be done by painting with the whitest paint obtainable all contiguous surfaces which cannot be seen from the specified point of observation. Thus in some cases it is of advantage to apply white paint to certain portions of the deck and to the under sides of overhanging superstructures. In some cases it may not be possible even by use of white paint to sufficiently lighten shadows. One instance of this is found in the case of the shadow in the throat of a ventilator. In such case a surface which receives sufficient illumination may be interposed between the point of observation and the shadow to be eliminated.

The essential points of this section may be summarized as follows:

(1) The background to be considered is composed entirely of sky.

(2) This area of sky to be considered subtends an approximate visual angle of 45′ in the vertical direction, of 3° in the horizontal.

(3) This area is very nearly uniform in brightness and color.

(4) The object (the observed boat) is not in general uniform in brightness and color.

(5) By special treatment a close approach to uniformity can be obtained.

(6) For low visibility an object viewed against a background which is uniform in brightness and color should also be uniform and of the same brightness and color as the background.

(7) For low visibility an object viewed against a background not uniform in brightness and color should exhibit a distribution of brightness and color similar to that prevailing in the background.

(8) Visibility due to lack of uniformity may be measured by the same general method, *i.e.*, the superposition of a veiling glare over object and background.

EXPERIMENTAL RESULTS.

The theory upon which the measurement and specification of visibility is based having been briefly considered and an instrument devised by means of which the visibility of any object may be measured, it remains now to discuss the practical application of these methods to actual cases.

It has been shown that the background available in case of the observation of a surface craft from a submarine is composed almost entirely of sky and that this sky is uniform in color and brightness. For low visibility the boat must also be uniform. Hence a flat board, cut so as to represent the profile of the boat to be observed and painted uniformly represents satisfactorily, from the standpoint of visibility, the optimum condition for low visibility. While such models do not represent the actual appearance of a structure distributed in three dimensions, they do represent the ideal which may be approached by a system of painting which eliminates as nearly as possible all highlights and shadows. Such profile models are, therefore, quite satisfactory for this phase of the work, which deals with the determination of the best brightness and color for the production of low visibility.

Referring now to the theoretical treatment and the nomenclature adopted, it will be seen that the conditions for invisibility are that:

$$B_1 = B_2 = R_2 E_2,$$
$$H_1 = H_2,$$
$$S_1 = S_2.$$

The factors B_1, H_1 and S_1 are natural characteristics of the particular sky background being considered and hence are fixed. The term E_2 is also a factor beyond our control. The three factors subject to control are, therefore, R_2, H_2 and S_2, and it is with the experimental determination of the best values of these three terms for various conditions of the weather that this section deals. It is convenient to divide the work into parts:

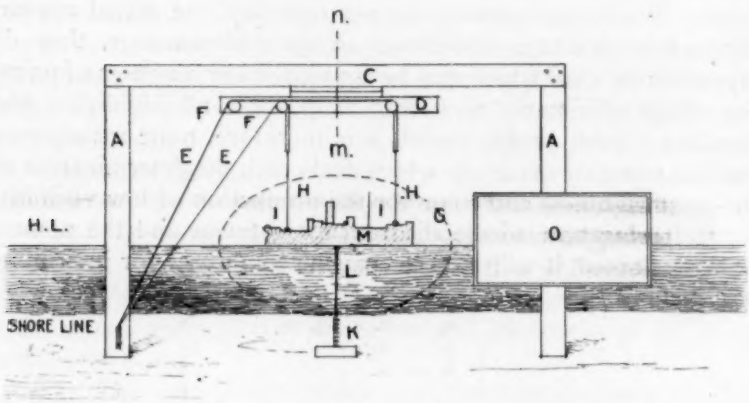
(1) The determination of R_2.

(2) The determination of color (H_2 and S_2).

The experimental work was carried out at Rochester, N. Y., on Lake Ontario, and at sea. In order to obtain natural lighting conditions and to use as a background a portion of sky just above a water-line sky, a station was established on the shore of Lake Ontario. To hold the models in proper position for observation,

a rack with an arrangement for suspending the models was erected. This rack, illustrated in Fig. 6, was erected as close to the water's edge as possible. The two uprights, *A*, *A*, were connected at the top by the crosspiece *C*. The member *D* was suspended from *C* and so arranged that it could be rotated in a horizontal plane about the vertical axis represented by the line *mn*. To the ends of the sash cords, *E*, *E*, running over the pulleys, *F*, *F*, on the member *D*, were attached fine piano wires, *H*, *H*, terminating in hooks, *I*, *I*. In placing a model in position for observation the hooks, *I*, *I*, were inserted into the eyes located along the top of the model, *M*, and an attendant operating the

FIG. 6.



The model rack.

cords raised the model to such a position that from the point of observation the lower boundary of the model appeared to be coincident with the horizon line, *HL*. One end of a strong spiral spring, *K*, was attached to the ground directly below the model, the other end termination in a piano wire leader, *L*, which was hooked into an eye on the bottom of the model, thus preventing the model from being displaced from the desired position by any wind that might be blowing at the time. On one of the uprights the test plane, *O*, was placed at the same height as the model, thus permitting the test plane to be brought into the field by simply changing the orientation of the visibility metre on its tripod.

The point Station 1, Fig. 7, from which most of the observations were made, was due south from the model and at such a dis-

tance that the visual angle subtended at the eye by the model was equivalent to that subtended by a boat 300 feet long when at a distance of 6000 yards from the observer. Readings, however, were taken at other points, Stations 4 to 7, such that the equivalent distance for the 300-foot boat was varied from 2000 to 18,000 yards. By rotating the member *D*, readings could be taken with the boat at any angle to the axis of sight, thus giving visibility values for a boat at any desired course. Observations were also taken from points southwest, Station 2, and southeast, Station 3, from the model and with the models at various angles,

FIG. 7.

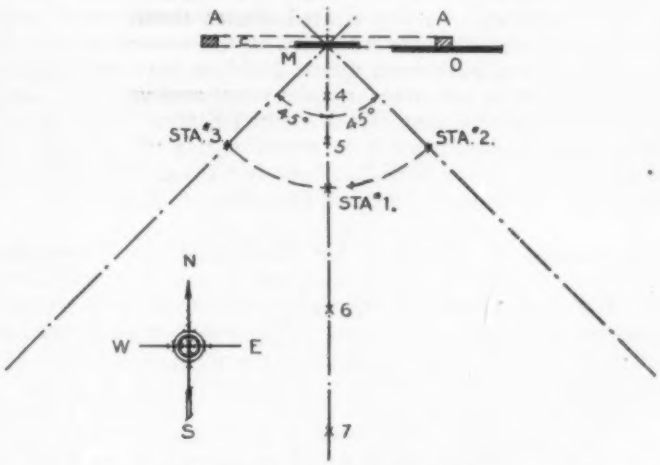


Diagram of the observation stations.

to the line of sight. Figs. 5 and 6 are not drawn to scale. The actual distance between the model and the nearest point of observation, Station 4, was approximately 100 feet, while the distance between the centres of model and test plane was 8 feet, so that the model set parallel to the test plane and the line of sight was practically perpendicular to both test plane and model. The models used were approximately 5 feet long by 6 inches high. Therefore, an actual distance of 50 feet between model and point of observation causes the same visual angle to be subtended by the model as would be subtended by a ship 300 feet long at a distance of 1000 yards. Station 1, upon which the great majority of observations were made, was at a distance of 300 feet from the model.

(To be concluded.)

Motor Cars at Home and Abroad. (*Machinery,* London, vol. xiv, No. 354, p. 446, July 10, 1919.)—There is a motor vehicle registered in the United States for every twenty-four persons; in Canada the proportion is probably one to each fifty; in England, one to two hundred; in Denmark, one to three hundred; and in France, Belgium, Holland, Switzerland, and Germany, about one to every four hundred. In 1917 it was estimated that Italy had one car to each 1000 of the population; Portugal, to each 1690; Spain, to each 1900; Austria-Hungary, to each 2650; and Russia, to each 5000. In Australia there was one car for each 140 of the population, and in South America as a whole, one for each 1430. Many a minor city in the United States has more cars than the whole of China or Japan. France for many years headed the list of automobile exporting nations, followed by Great Britain, the United States, Italy, Germany, and Belgium. In the United States the domestic requirements were so great that the majority of the cars were absorbed at home. British and European motor builders have multiplied their plant and equipment ten times in four years and yet their combined capacity is still behind that of the United States. It is stated that one American factory intends to manufacture within one year as many cars as the entire British output for 1914. The price of this car is expected to be approximately from $600 to $750.

Preparation of Glycerol by Carbohydrate Fermentation. SCHWEIZER. (*Helvetica Chim. Act.,* vol. ii, p. 167, 1919.)—Pasteur in 1857 found that ordinary alcoholic fermentation is attended by the production of a small amount of glycerol. He obtained nearly four parts by weight from 100 parts of sugar. Later, Laborde made investigations as to the influence of the amount and character of the yeasts used, and obtained about double the yield that Pasteur obtained. The production of glycerol depends largely on the nutritive powers of the solution. High nutrition increases the yield, but it seems to have no correlation with the production of alcohol. Schweizer's most successful experiments were carried out with the addition of sodium sulphite as a reducing agent, it having been found that this is favorable to the production of glycerol. The following experiment is given. Fifty grammes of sucrose were dissolved in 500 c.c. of water, 10 grammes of pressed yeast added, and then 30 grammes of sodium sulphite in three portions. After twenty-four hours' fermentation the glycerol produced amounted to 18.72 per cent. of the sucrose used. It is not stated whether the sodium sulphite was crystallized or anhydrous, but probably it was the former. A similar experiment carried out with active aëration gave only half the yield of glycerol. Schweizer states that the method was used by the Central Empires as a source of glycerol on account of the shortage of fats. No biologic examinations of the yeasts are recorded, nor is any statement made as to production of glycerol from the cheaper carbohydrates. An interesting field of research must be offered along this line. H. L.

AIR FLOW OVER REAR DECK OF BATTLESHIP PENNSYLVANIA.*

BY

A. F. ZAHM, Ph.D.

Bureau of Construction and Repair, Navy Department.

In January, 1918, the Navy model of the battleship *Pennsylvania* was tested in the $8' \times 8'$ wind tunnel to determine aerodynamical and structural conditions suitable for landing light airplanes upon the after-deck of the full-scale ship. The model was tested first in its natural condition, then with a shelving deck placed above the rear part in a manner presently to be described.

The experiments here outlined were made by Messrs. R. H. Smith, W. H. Gornall and G. J. Chaillet; the illustrations were prepared by Mr. M. T. Birch—all members of the Aeronautics Staff. Major B. L. Smith, U. S. M. C., indicated what explorations should be made and under what conditions.

TEST OF MODEL IN ITS NATURAL CONDITION.

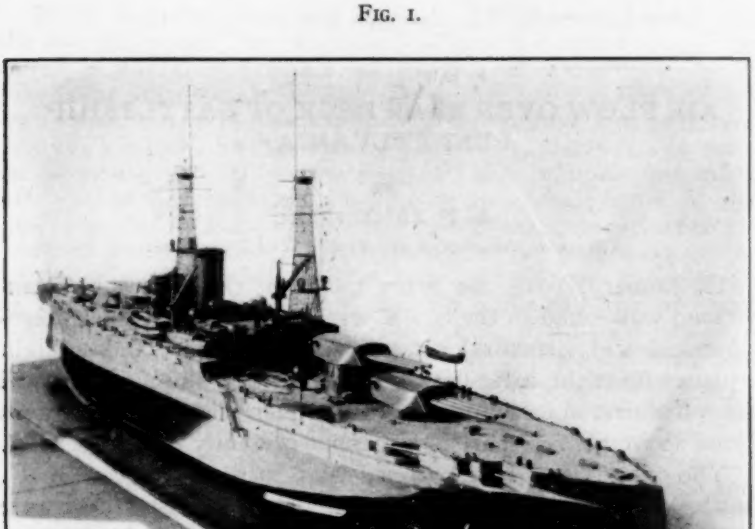
Battleship and Original Model.—Fig. 1 gives the general appearance of the *Pennsylvania* model constructed to a scale of 1 in 48. The chief dimensions of the ship are: length 600 feet, beam 97 feet, height of the rear deck above the water line 25 feet.

Method of Test.—The unaltered model was first placed upright on the floor of the tunnel, so that its plane of symmetry was midway between the side walls, and its rear deck was under the window in the tunnel ceiling, where it could easily be observed and photographed. The speed of the general air stream was then held at 30 miles per hour, and the velocity about the model was measured with a pitot-tube held in the vicinity of the stern at distances corresponding to 20-foot intervals horizontally rearward, and 5, 15, and 25 feet vertically, above the main deck of the full-sized craft. Table I and Fig. 2 give the wind speed and the lines of equal velocity at these stations; first in the plane of symmetry, then in a parallel plane 24 feet from it.

Fine steel wires were then strung across the tunnel at rear-

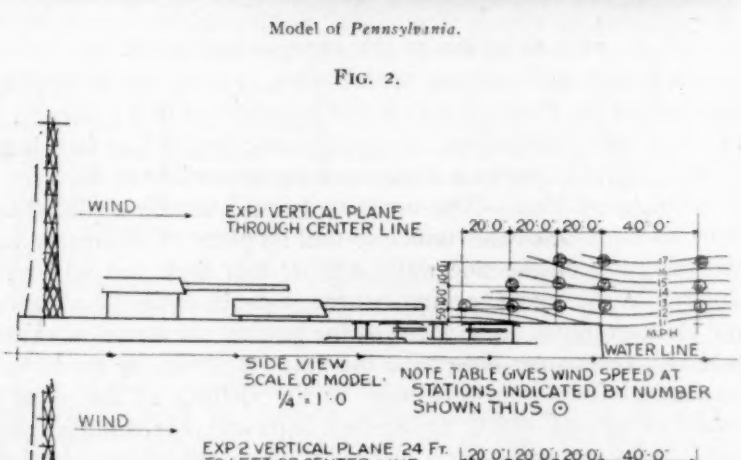
* Communicated by the Author.

FIG. 1.



Model of *Pennsylvania*.

FIG. 2.


WIND
EXP1 VERTICAL PLANE THROUGH CENTER LINE
20'0" 20'0" 20'0" 40'0"
M.P.H.
WATER LINE
SIDE VIEW
SCALE OF MODEL 1/4" = 1'0"
NOTE TABLE GIVES WIND SPEED AT STATIONS INDICATED BY NUMBER SHOWN THUS ⊙
WIND
EXP 2 VERTICAL PLANE 24 Ft. TO LEFT OF CENTER LINE
20'0" 20'0" 20'0" 40'0"
M.P.H.
WATER LINE
SIDE VIEW
SCALE OF MODEL 1/4" = 1'0"

Flow over rear deck of *Pennsylvania* at 30 M.P.H.

ward distances corresponding to 48 feet on the full-size craft, and to these were moored, at 8-foot intervals, short silk threads, as portrayed in Fig. 3. With long fluttering threads cleaner photographs were obtained by stopping the wind after the threads had assumed their natural positions. Fig. 4 illustrates the direction of flow, thus observed, in three horizontal planes whose distances above the rear deck were, respectively, 24, 36 and 48 feet.

The model was then held with its plane of symmetry horizontal, its deck under the ceiling window, and its base screwed to planking parallel to the side wall. The same general scheme was

TABLE I.

Battleship Pennsylvania Model. Velocity of Air over Rear Deck and Stern. Wind Speed 30 Miles per Hour.

Station	Air speed in miles per hour at various stations	
	In vertical plane through centre line	In vertical plane 24 feet to left of centre line
1	11.5	20.4
2	12.2	19.1
3	11.1	....
4	10.6	....
5	9.9	....
6	14.6	24.6
7	14.1	22.4
8	13.7	23.4
9	13.3	....
10	16.3	25.1
11	16.5	25.7
12	14.9	25.4

employed for observing the flow; first in the plane of symmetry, then in a parallel plane 24 feet distant on the port side, as shown in Fig. 4 and Fig. 5.

Results.—The equal-velocity lines in Fig. 2 and the direction lines in Fig. 4 show a pronounced interruption of the airflow near the deck, due mainly to eddies set up by the rear turret. This disturbance is unchanged when the rear turret is swung through 90°, as illustrated by Fig. 6.

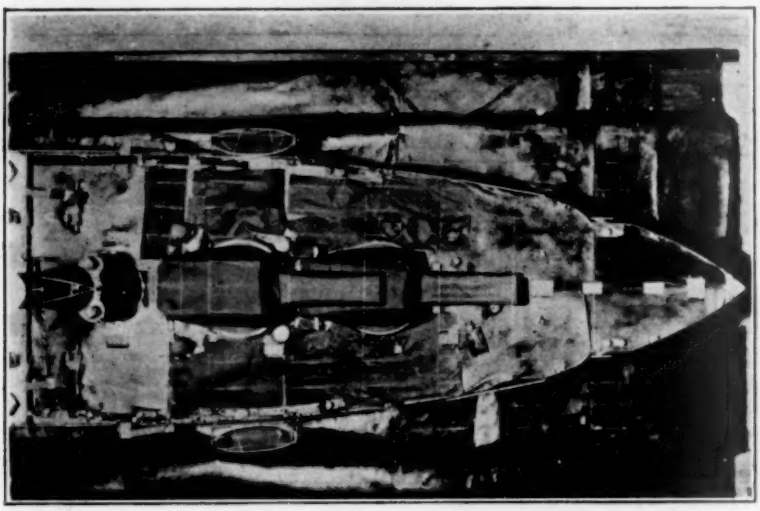
Conclusion.—Difficulty would be experienced in landing airplanes in the disturbed air over the rear deck of the *Pennsylvania* battleship in its unaltered condition. A shelving deck above the

plane of the rear turret would insure a smoother flow of the air. It was, therefore, requested that such a deck be added to the model and given a test in the tunnel.

TEST OF THE MODEL PROVIDED WITH SHELVING DECK.

The Shelving-Deck Model.—The original model was now tested; first with a small shelf deck, then with a larger one. In the scale of the full-size craft these measured, respectively, 80′ × 120′ and 100′ × 180′. The smaller shelf deck was placed 5 feet above

FIG. 3.



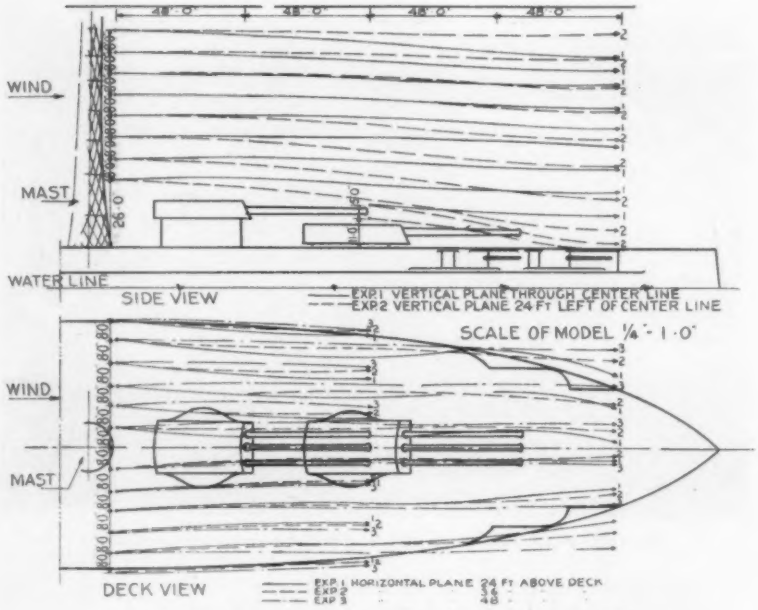
Short threads over rear deck of *Pennsylvania* model.

the main deck, and extended from a point just under the guns of the rear turret to a point just over the stern. The larger deck was 10 feet above the main deck and extended from the mast, rearward, over both turrets and over the stern.

Method of Test.—Substantially the same method of tracing the direction of the airflow was used with the model having the shelving deck as with the original one. Fig. 7 shows the arrangement of the wires and the general appearance of the larger deck. The wind speed for these latter tests was 20 miles per hour.

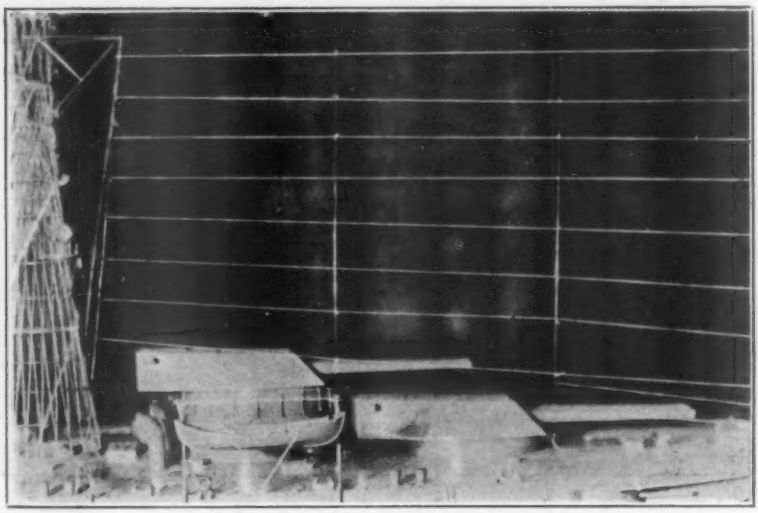
Results.—Fig. 8 reveals a continued disturbance of a minor

FIG. 4.



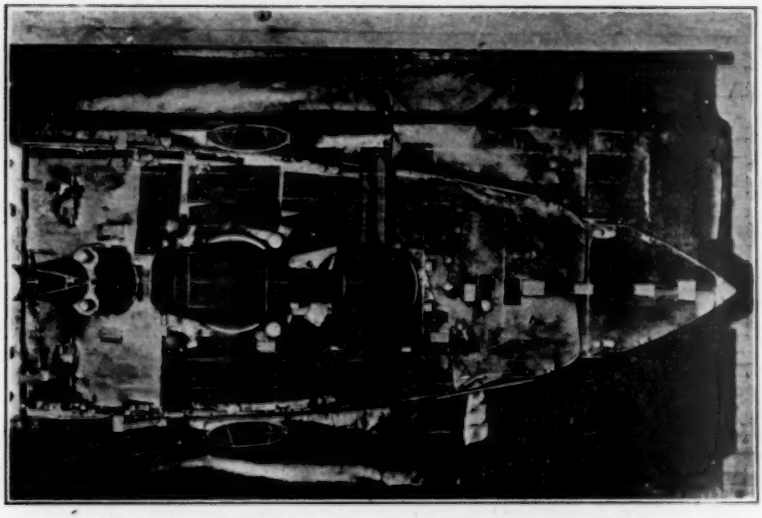
Direction of air flow over rear deck of *Pennsylvania* model.

FIG. 5.



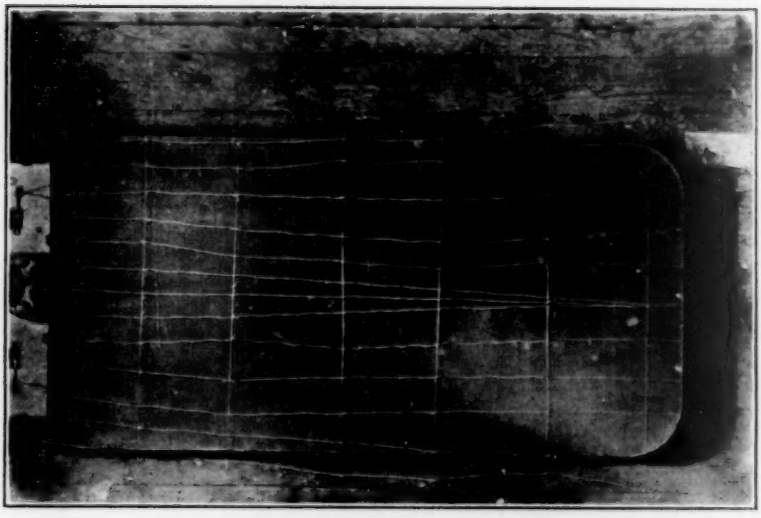
Stream-line threads in plane of symmetry over rear of *Pennsylvania* model, lying on its side.

FIG. 6.



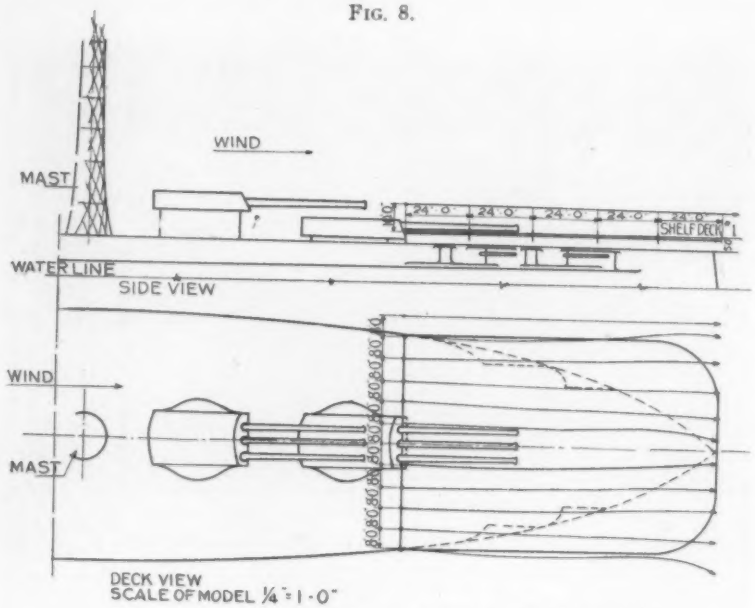
Flow over rear deck of *Pennsylvania*, with rear turret set athwart ship.

FIG. 7.



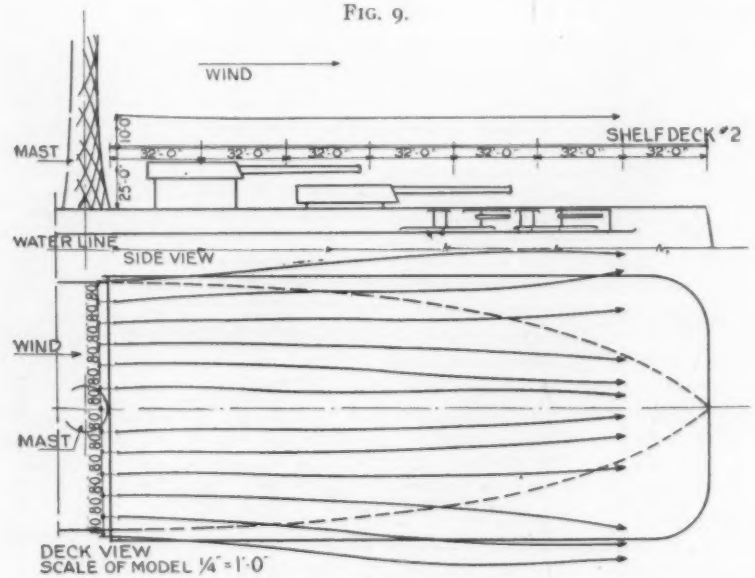
Shelving deck and threads over rear of *Pennsylvania* model.

FIG. 8.



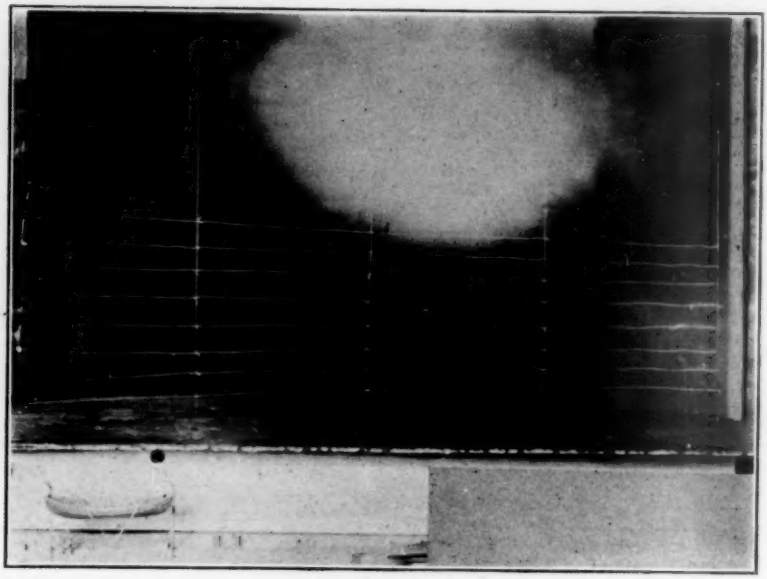
Direction of flow over shelf No. 1 at rear of *Pennsylvania* model.

FIG. 9.



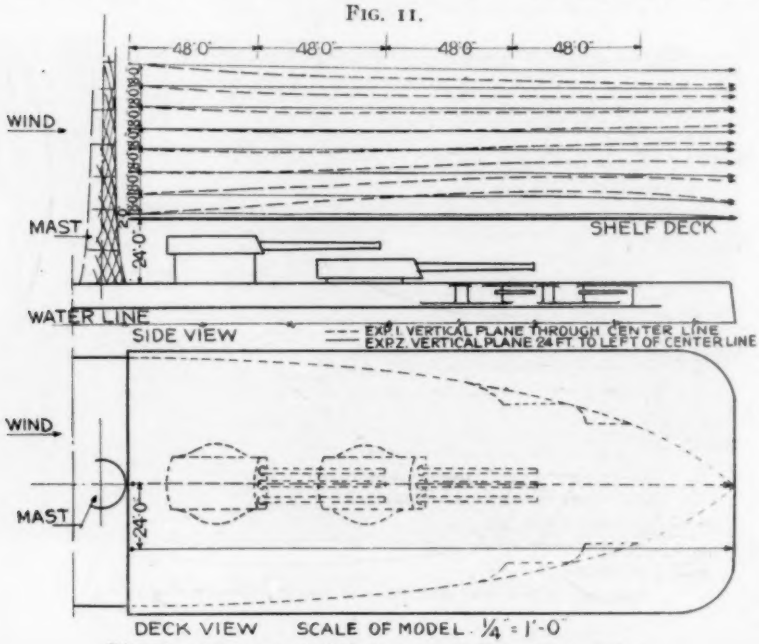
Direction of flow over shelf No. 2 at rear of *Pennsylvania* model.

FIG. 10.



Air flow in plane of symmetry over rear shelf-deck of *Pennsylvania* model, lying on its side.

FIG. 11.



Direction of flow over shelf deck at rear of *Pennsylvania* model.

character at a level 15 feet above the main deck of the ship when furnished with a smaller shelf deck. This is probably due to irregular flow around the hull of the ship. Fig. 9 outlines the direction of flow above the larger shelf deck, in a plane 35 feet above the main deck, and indicates a slight tendency of the air stream to spill over the sides of the shelving deck. The ample beam of the vessel insures a uniform air stream broad enough to afford, with either shelf, a favorable directional flow for landing small craft upon the ship.

Further Data.—In a subsequent test, maps of the airflow with the shelf deck in position were determined at 30 miles an hour for the plane of symmetry of the vessel, and for a parallel plane half way out to the edge of the shelf on the port side. It was assumed that the flow in the corresponding plane on the starboard side would be the same. The large shelf deck described in this account was used.

Figs. 10 and 11 show the streamlines for these two planes. The full lines of the diagram indicate that the flow is fairly level and uniform in the planes at either side of the centre line. In the plane of symmetry the flow, indicated by the dotted lines, is considerably less uniform in speed and direction. It would appear from this that the poise of the airplane would be steadiest when flying along the centre line, and not very steady when flying to either side thereof.

Concrete Freight Car. (*Machinery*, vol. xxv, No. 12, p. 1114, August, 1919.)—The first plans for the manufacture of reinforced concrete freight cars dates from 1909, when a patent for such a car was granted. Recently, however, a car of the gondola type was built by a western concern and tested under service conditions. The tests of the car, both empty and loaded, demonstrated its practicability for rough service. In the test without a load, it withstood extremely rough handling and switching. Then the car was loaded with fifty-five tons (10 per cent. overload) of sand and turned over to a switching crew for service handling, which it also withstood without injury. Some advantages claimed for the concrete car are that it will not need painting, will practically eliminate maintenance charges, and will last much longer than the wooden car. As it is unaffected by its cargo, it is better adapted for hauling slag and ashes than a steel car. Plans are said to be under way for the quantity manufacture of these cars. The first one was built with the coöperation of the United States Railroad Administration, which is an indication that extensive production may not be delayed very long.

Increased Efficiency Taught by the War. (*Machinery*, vol. xxv, No. 12, p. 1129, August, 1919.)—The war has undoubtedly taught an important lesson in regard to the increasing of efficiency in machine building plants. There are numerous cases on record where to-day manufacturers are turning out a much larger product than five years ago with the same force and equipment. The production per man and machine has been increased by stopping many small leaks. In one instance on record, more machines are being built by a force 75 per cent. of the normal than were formerly built by the full force. In another instance, the production is being maintained by a force two-thirds that of five years ago. Another case may be mentioned where the production has been doubled without materially increasing either the force or the equipment. It is evident that such economies and increased efficiency are necessary in order to cope with the increasing wages, taxes, and costs generally.

The advantages of salvaging small tools such as milling cutters and reamers seem, however, to have been forgotten with the advent of peace. The shops in the Detroit district that devoted themselves to this class of work report that the reclaiming business is quite dull and that at the present time only new tools are wanted and no one is paying any attention to the saving made possible by salvaging. Some manufacturers who devoted themselves to the salvaging of reamers and milling cutters, therefore, have gone into the regular cutter and reamer manufacturing business. Whether there is not a definite economic loss to the nation as a whole in the dropping of the salvaging business is difficult to decide, because it is evident that with the reduction in the prices of high-speed steel the saving by salvaging becomes less, but it is nevertheless likely that a substantial saving could be effected if users of tools utilized the salvaging processes. A comparison between the conditions at this time and during the war in regard to the salvaging of tools would prove interesting.

Burnt Clay in Concrete Ships. (*United States Geological Survey Press Bulletin No. 417*, July, 1919.)—Burnt clay was used in 1918 for the first time as an aggregate for concrete in building ships. The war made it imperative that steel be conserved as much as possible, and the experiment of building seagoing ships of concrete was undertaken. It became necessary to make the concrete as light in weight as possible, so various light materials, including pumice, were tried. An aggregate made of burnt shale or clay proved to be a very acceptable substitute for stone and gravel in concrete, and its use reduced the weight per cubic foot from about 150 pounds to 118 pounds or, in some mixtures, even to 100 pounds. This aggregate was made near Birmingham, Ala., at Hannibal, Mo., and at Los Angeles, Calif. Its manufacture was not begun until late in the year, but enough was made to construct a 3000-ton concrete ship, the *Atlantis*, which was launched in December at Brunswick, Ga.

SPECTRAL ENERGY DISTRIBUTION IN THE ACETYLENE FLAME.*

BY

W. W. COBLENTZ, Ph.D.

Associate Physicist, Bureau of Standards.

IN previous papers the writer [1] published data on the spectral energy distribution of the acetylene flame.

In one of these papers [2] an estimate is given of the accuracy attainable in making the observations. It is based upon the deviations of the observations from the mean value; and it is shown that whereas in the red end of the spectrum an accuracy of 0.5 per cent. is attainable (provided the flame stays constant) that an accuracy of 10 per cent. is hardly attainable in the violet. Unfortunately no mention was made of the difficulties and uncertainties in reducing these observed data from the prismatic into the normal spectrum. The purity and slit width factors were probably accurate to 1 per cent. The greatest uncertainty was the correction for absorption in the glass prism or the silver mirrors (or both) in the violet end of the spectrum. Corrections must be made also for diffuse light.

To overcome the difficulties of absorption a spectrometer, consisting of a quartz prism and two plano-convex lenses, was used for measurement in the violet. Not being achromatic, a correction had to be made for change in aperture, with change in focal length for different parts of the spectrum. A recent examination shows that the published data were probably overcorrected (in the violet) for change in aperture; and the utility of such an instrument for making such measurements is to be questioned.

The spectral energy data published by the writer [3] were obtained from a composite curve consisting of measurements from 0.5μ to 75μ made (first) with a mirror spectrometer and fluorite prism, and (second) a glass lens spectrometer with flint glass prism (the absorption of which has been determined), supplemented by measurements, from 0.4μ to 0.5μ, made with (third) the quartz lens spectrometer just mentioned.

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* Communicated by the Author.

[1] Coblentz, *Bul. Bur. Stds.*, 7, p. 253, 1911; 13, p. 355, 1916.

[2] *Bul. Bur. Stds.*, 7, p. 252, 1916.

[3] *Bul. Bur. Stds.*, 13, p. 355, 1916.

Inspection of the published curve [4] illustrating these data shows a divergence in the region of 0.48μ. Computations made at that time indicated that for the region of 0.48μ to 0.75μ the spectral energy distribution was that of a black body at about 2100° C. (2370° K.); though at that time no significance was attached to it, and hence no mention was made of the fact.

The data presented in the present paper are based upon a careful study of the original spectral energy curve. Some of the deviations noted in columns 2 and 3 of Table I resulted from variations in reading the data from the curves. The data at 0.4μ to 0.5μ obtained with the quartz prism are now given, but little weight, owing to the question of aperture correction. The revised data are given in column 3, while column 2 gives the data as previously published. They are practically the same except in the violet.

In a recent inter-laboratory comparison, by color matching the acetylene flame against a tungsten lamp, Hyde and his collaborators [5] have placed the color temperature of the Eastman Kodak standard acetylene flame at 2360° K. Within the experimental errors of observation the spectral energy distribution of several series of observations of this flame was found to be the same as that of the burner (with 8 mm. slit) used by the writer in the visibility of radiation measurements.

The spectral energy curve of a black body of 2360° K. was kindly computed by Mr. Herbert Kahler and carefully superposed upon the observed data, using a scale which was sufficiently large to eliminate errors (0.5 per cent.) in drawing the curves and reading off the data. These data are given in column 4. Column 5 gives the ratios of observed to computed data for 2360° K. It will be noticed that between 0.48μ and 0.75μ, which is the region in which the radiometric measurements are of importance in the visibility of radiation work, there is as close agreement (± 2 per cent.) between the computed and observed data as can be expected—for, when the errors incident to color match as well as radiometric observations are considered, it will no doubt be conceded that the color match, as well as the radiometric work, has its limitations.

While the writer makes mental reservations as to the efficiency

[4] *Bul. Bur. Stds.*, 13, p. 361, Fig. 3.
[5] This JOURNAL, 188, p. 129, 1919.

of the color match test in the extreme violet of the spectrum where the eye is very insensitive, and subject to great decrease in sensitivity with age, he concurs in the recommendation made by Hyde that the spectral energy distribution of the acetylene flame (using a certain type of burner) in the visible spectrum is satisfactorily represented by the black body curve at 2360° K., as given in Table I. A difference of 10° or even 50° K. is hardly

TABLE I.

Spectral Energy Transmission of a Cylindrical Acetylene Flame; Observed and Computed Using Wien's Eq., C=14350 and T=2360° K.

Wave length	E Observed 1911–1916	E Revised 1919	E′ Computed	100E′/E
.450	11.5	10.	9.2	92.
.460	13.0	12.	11.2	93.
.475	16.0	15.0	14.6	97.3
.500	21.9	21.0	21.1	100.5
.520	27.9	27.5	27.3	99.3
.525	29.5	29.2	29.2	100.0
.540	35.0	34.6	34.6	100.0
.550	38.9	38.9	38.9	99.8
.560	42.9	42.9	43.1	100.4
.575	49.8	49.8	49.9	100.2
.580	52.2	52.2	52.4	100.3
.600	62.1	62.5	62.9	100.6
.620	73.0	73.3	74.0	101.1
.625	75.7	76.1	76.8	100.8
.640	84.7	85.0	86.0	101.1
.650	91.1	91.2	92.1	101.0
.660	97.4	97.6	98.5	100.7
.675	107.5	107.5	108.0	100.4
.680	110.9	110.9	111.3	100.7
.700	124.6	124.1	124.1	100.0
.720	138.5	135.7	137.2	99.8
.725	141.9	141.0	140.5	99.6
.740	152.0	151.0	150.2	99.5
.750	158.9	157.9	157.2	99.5

to be considered in view of the great divergence in burners, the effect of humidity, quality of gas, etc.

The independent check by Hyde and his collaborators confirms the direct radiometric observations on the spectral energy distribution of the acetylene flame, in the region of 0.5μ to 0.75μ, as used in the visibility of radiation work and leaves the visibility data [6] unchanged.

WASHINGTON, D. C.,
July 24, 1919.

[6] *Bul. Bur. Stds.*, **14**, p. 168, 1917.

Dyestuffs by New Methods. (*Weekly News Letter*, U. S. Department of Agriculture, vol. vi, No. 51, p. 4, July 23, 1919.)—Cheaper proceses for the manufacture of a number of dyestuffs and medicinal preparations will result, it is believed, from discoveries made by experts of the United States Department of Agriculture who have been investigating ways of making certain sulphonic acids. With a view to helping the chemical industry of the country, the department is offering to coöperate with manufacturers in establishing the process on a commercial scale. The expenses of installation are to be borne by the manufacturing concerns coöperating. Experts of the color laboratory of the Bureau of Chemistry will be assigned to the plants and will assume control of the undertaking.

In all such undertakings, the stipulation will be made by the department that the manufacturing concern is not to divulge anything pertaining to the original process or to any that may be developed later, but that the right to patent any or all of these remains in the Department of Agriculture, these patents, if they are allowed, to be dedicated to the free use of the Government and the public.

In the laboratory experiments the sulphonation of a number of hydrocarbons has been studied and in some cases the laboratory work has reached a stage that large-scale experiments are necessary to prove the value of the process. The work on benzene is most advanced. Sulphonated benzene is used in the manufacture of resorcinol and of synthetic phenol. The laboratory work on the sulphonation of other hydrocarbons is nearing completion.

Durability of Untreated Piling Above Low Tide. (*Technical Notes*, Forest Products Laboratory, Madison, Wisconsin.)—In tidal waters the portions of piles above mean low tide, although completely immersed only part of the time, may be practically saturated all the time. Wood constantly saturated with water is not subject to decay, and this fact makes the height to which saturation extends above low tide a question of considerable interest to the designing engineer.

The opinion of a number of engineers and construction companies, expressed in response to inquiries by the Forest Products Laboratory at Madison, Wis., is that untreated piling in water not infested with marine wood-borers will remain sound indefinitely if cut off at half-tide. This height ranges in various ports from 2.3 to 4.5 feet above low water. At certain places on the Atlantic coast, piles cut off at the height of half-tide are still sound after from fifty to one hundred years of service.

Untreated piling is destroyed by marine borers more rapidly than by decay, and the information given would, of course, have no practical use where these organisms are active.

NOTES FROM THE U. S. BUREAU OF STANDARDS.*

TESTS OF EIGHTEEN CONCRETE COLUMNS REINFORCED WITH CAST IRON.[1]

[ABSTRACT.]

THE columns were made by Mr. L. J. Mensch, Contracting Engineer, of Chicago, and tested in the Pittsburgh Laboratory of the Bureau of Standards. Although such columns have been in use abroad for several years the tests under discussion are the first of this type which have been made in America.

These columns were 12 inches in diameter (inside 1⅛-inch pitch, 8-guage wire spiral) and were reinforced longitudinally with steel rods and cast-iron tubes. The cast-iron tubes located in the centre of the columns varied in outside diameter from 5 to 7 inches with wall thickness of ⅝ to 1 inch. The column lengths varied from 6 to 14 feet. Tests were made on samples of the cast iron; also on the concrete used which was proportioned by volumes and consisted of one part cement, one part sand, and two parts gravel, hand-mixed.

The behavior of these columns under loading was similar to that of the ordinary type of steel-reinforced columns. Incipient failure was in all cases accomplished by scaling of the outer shell which finally spalled off at the surface of the spiral. This was followed by failure in tension of the spiral reinforcing at the maximum load sustained by the column. The protective shell outside the spiral fails at a strain of .00145 (ave.). This is the same strain at which the test cylinder failed.

The maximum strength of the column is not quite equal to the strength of the cast-iron reinforcement tested independently plus the strength of the usual type of spirally reinforced column. The cast-iron reinforced column has, however, a much less area of concrete.

The columns commenced to scale at 70.4 per cent. (ave.) of the maximum load. Two columns of the same series without cast

* Communicated by the Director.

[1] Technical paper 122.

iron commenced to scale at 89.9 per cent. (ave.) of the maximum. The average maximum total load sustained by the various types reinforced with cast iron and of the same length (10 feet) as the two plain spiral reinforced columns was 81.5 per cent. greater than was sustained by the plain spiral columns. Filling the hollow core of the cast-iron tubes apparently adds 6500 pounds for each square inch of cross section thus filled. Varying the radius of gyration of the cast-iron tubes, the net cross section area remaining constant does not apparently affect the ultimate strength of the column. Cast-iron I sections were used instead of tubes in two of the columns, the results comparing favorably with the tube columns having the same percentage of cast iron.

The following formula for variation of strength with length is derived from these tests:

$\frac{P}{A} = 12{,}150 - 20\,l$, in which

P = mean stress upon total area of column inside the spiral.

A = total area as above.

l = length of column in inches.

In view of the general behavior of spirally reinforced columns just preceding failure it is suggested that a superior type might be developed if the protective shell outside the spiral were applied after the column has been cast and the forms removed. This shell should be of some material possessing the necessary heat insulating qualities and the ability to withstand without failure a considerably greater strain than .0015 (the strain at which unreinforced concrete fails). This method of construction would also make possible a much greater accuracy in the placing of the spiral.

The complete report of these tests contains numerous tables, photographs and diagrams with a discussion of the design of the columns and the results obtained.

NOTES FROM THE U. S. BUREAU OF CHEMISTRY.*

ILEX VOMITORIA AS A NATIVE SOURCE OF CAFFEINE.[1]

Frederick B. Power and Victor K. Chesnut.

[ABSTRACT.]

SEARCH for a native source of caffeine has demonstrated that an abundant supply may be obtained from a native plant, *Ilex vomitoria*, Aiton. Assays [2] by a method developed by the authors showed the presence, in most cases, of about 1 to 1.5 per cent. of caffeine in dried leaves. Although considerable differences in the caffeine content of the leaves of the plant have been found to exist, these are doubtless attributable to varying conditions of soil and climate. It would, therefore, appear that by the cultivation of the shrub under the most favorable conditions the supply of material for the production of caffeine could be increased to any desired extent.

So far as has at present been ascertained no other North American species of *Ilex* than that above mentioned contains caffeine, and this substance is not contained in the leaves of the European holly, *Ilex aquifolium*, Linné.

Blasting Down Chimneys. (*Engineering World*, vol. xv, No. 3, p. 49, August 1, 1919.)—Following is a method for blasting down chimneys that has been found effective by many engineers. First, remove half a brick in one corner of the chimney at the floor level. Crumble a pound of dynamite and pack it tightly into the back of the hole. Insert a cap and fuse in the charge. Fill the hole with wet sand and pile more wet sand out on the floor, covering the hole entirely to the depth of about 1 foot. Pack the sand down tight so as to get as much resistance to the dynamite as possible. One shot will topple over the chimney as a rule. If the first shot only weakens the structure, however, remove another half brick at the opposite corner and repeat the operation. The second shot, it is claimed, never fails.

* Communicated by the Chief of the Bureau.

[1] Published in *J. Amer. Chem. Soc.*, **41**, 1307–12, August, 1919.

[2] "An Improved Method for the Quantitative Determination of Caffeine in Vegetable Material." Frederick B. Power and Victor K. Chesnut, *J. Amer. Chem. Soc.*, **41**, 1298–1306, August, 1919.

Prospects of Re-habilitation in Germany. (In the August issue of *The Journal of Industrial and Engineering Chemistry.*)—Corporal Richard D. Zucker, a member of the American Chemical Society, and at the time of writing, with Army of Occupation in Germany, presents his views as to the probabilities of early re-habilitation of the German industrial activities. These depend, he says, largely on opportunites to get certain classes of raw materials, such as copper, tin, nickel, cotton, rubber, gums, essential and fixed oils. Lead and zinc are in good supply within the nation, but the bauxite deposits upon which the aluminum industry depended formerly are mostly in French territory, and it is doubtful if France will allow free purchase, and further, the United States and Canada, well supplied with the mineral, will prove powerful competitors. Zucker calls attention to the fact, which must never be forgotten in discussing the German problem, namely, that the dye-stuff industry can be converted at short notice into a high explosive and poison-gas industry.

One thing which Germany fears in a commercial way is the competition of Japan. Since 1913, Japan's exports to Australia alone increased eight-fold. There is a bitter feeling on account of the strides that Japan has taken in the export of toys, fancy wares, etc., to the United States, South America, Australia, and Europe. The fact that Germany, being closely engaged in warfare, gave Japan an excellent opportunity to expand her business connections, now causes Germany to apply the term " Yellow Peril " to the industries.

Corporal Zucker's observations lead him to suspect that the present leaders of Germany have not wholly abandoned the dream of world domination, and that vigilance will be the only way in which the world can escape another colossal effort to establish the " Deutschtum " and impose " Kultur " on mankind.

H. L.

War and the Railways. (*The Baldwin Locomotive Works, Record No. 93,* 1919.)—After winning one of the greatest battles of the war, General Joffre is reported to have said: " This is a railway war. The battle of the Marne was won by the railways of France." And while this statement may, at first sight, appear to be extreme, it is literally true; for success or defeat, in a present-day battle, depends chiefly upon the rapidity with which large masses of men can be moved and the guns served with ammunition; and this must be accomplished by the railways, aided by motor trucks. The amount of ammunition expended during a period of intensive fighting has been almost beyond comprehension. In the attack and defense of Verdun, for example, approximately 60,000,000 shells, representing 3,000,000 tons of steel, were expended in thirty weeks; and the railways moved the greater part of this material to the firing line.

NOTES FROM THE RESEARCH LABORATORY WESTINGHOUSE ELECTRIC AND MANUFACTURING COMPANY.*

WIRE TESTING EXTENSOMETER.

By P. H. Brace.

An extensometer for testing wire and other thin sections has been developed at this laboratory. It consists essentially of a metal block to which two flexible side pieces are attached, the free ends of these carrying rollers. The wire to be tested is clamped at the block and passes between the rollers. Extensions of the wire between the blocks and rollers due to loading the wire results in rotation of the rollers which are held in contact with the wire by the flexibility of the side pieces.

Light from a small straight filament galvanometer lamp passes through a collimating lens to a mirror in the axis of one roller. From there it is reflected to a similarly placed mirror on the other roller, and reflected from there to a white scale divided into millimetres.

An extension of approximately .0001″ causes a movement of the spot of light to a distance of 1 millimetre on the scale. The position of the spot of light could be read to ⅕ mm.

The instrument has been in constant use over a period of several months with very satisfactory results. Specimens have been tested having sectional areas ranging from one-tenth to twenty millionths of a square inch, with satisfactory results. A patent application has been made covering this instrument.

THE MICROSTRUCTURE OF VERY LOW CARBON STEEL.

By R. E. Bedworth.

Very little information is available regarding the structures which may be produced in steel containing but a few hundredths of one per cent. of carbon. W. J. Brooke and F. F. Hunting[1]

* Communicated by the Engineer in charge.

[1] *Journal of the Iron and Steel Institute*, 1917, No. 2, p. 233.

report an unusual structure found in Armco iron quenched from between 899° and 832° C. They offer the explanation that it is a eutectoid thrown out of solution between these temperatures. A study was made at Yale University, under the direction of Prof. C. H. Mathewson, to throw some light on the nature of this constituent and to determine the effect of various forms of heat treatment on the structure of very low carbon steel. The material used was prepared by Dr. T. D. Yensen at the Westinghouse Research Laboratory by fusing electrolytic iron and carbon in a vacuum furnace. A series of exceptionally pure steels was thus made, with the carbon content ranging from 0.02 to 0.10 per cent. It was found that the "eutectoid" structures could be produced in this pure material by quenching from within the critical range. Further experiments produced conclusive evidence that the so-called eutectoid is not caused by impurities in the metal, but represents the transformation product of the austenite which is stable at the temperature of quenching.

When very low carbon steel is quenched from above A3 a large amount of free ferrite is found, the carbon being present in the form of sorbitic needles scattered throughout the material in the cleavage planes of the original austenite. Annealing at a temperature just below A1 for a long period of time brings about a separation of the sorbite needles into minute globules of cementite. Heating to just above A1, followed by slow cooling, changes the sorbite into very small grains of pearlite uniformly distributed between the small ferrite grains.

RESONANCE AND IONIZATION POTENTIALS FOR ELECTRONS IN THE MONATOMIC GASES ARGON, NEON AND HELIUM.

By H. C. Rentschler.

WHEN an electron is accelerated in a metallic vapor two types of inelastic impact are possible. The first type occurs when the moving electron displaces an electron of the atom without detaching it from the atom. The potential through which the moving electron must fall to acquire enough energy to produce this effect is known as the resonance potential. The second type of inelastic impact occurs when the colliding electron separates an electron

of the atom from the sphere of action of the atom and is said to produce ionization.

Experiments were carried out to determine whether the monatomic gases argon, neon and helium show both these types of inelastic impact. A large number of tests were made on these gases, using several methods. The curves obtained indicate that argon has a resonance potential of about 12 volts and an ionizing potential of about 17 volts, while helium and neon do not show the resonance effect.

PENETRATION OF MOISTURE IN INSULATING MATERIALS.

By C. J. Rottmann.

MANY samples of standard insulating materials have beeen tested for penetrability of moisture. A large variation in penetration is shown. Untreated papers show immediate penetration, whereas paper impregnated with various insulating compounds, treated cloth or condensation products like bakelite micarta, show very small penetration. None of the standard insulating materials may be called moisture proof.

Where the penetration of moisture is slow, little difference is noticed whether the sheet is in contact with water or the saturated vapor. Several thicknesses of bakelite micarta were used, the penetration in this case being nearly independent of the thickness up to $^1/_{64}''$, which is 1.5×10^{-6} gms. H_2O cm.^{2} per hour. Plotting gms. H_2O against time a small rapid increase in water is first observed followed by a much longer period, where practically no increase in water (time of penetration and dependent upon thickness), and then a gradually increasing amount of water, the slope of the curve remaining almost constant, which value is representative of the rate of penetration.

Several qualitative methods were first tried: (1) Colormetrically, by placing anhyd. $CuSO_4$ or $CoCl_3$ on glass plate upon which is placed the insulating material. Wet blotting paper is weighted down upon the sample and change in color noted upon penetration. Certain water sol. dyes may be also used with good results. (2) Electrically, by conductivity change with increase of moisture measured when insulating material is placed between Hg. surface and weak salt solution. (3) Quantitatively, by collection of moisture in P_2O_5 tube, or difference in pressure

of penetrated water vapor when released from liquid air trap by sensitive optical manometer method.

Method now in use may be briefly described as follows: Two 100-c.c. bulbs with stopcocks at necks and common connector for high vacuum system, each having flanged tube 1.5 cm. diameter leading from the side, are so arranged that the ground flanged surfaces fit together so that the apparatus is gas-tight. Through a ground joint in one bulb a weighed P_2O_5 tube is introduced. The opposite bulb contains a small amount of H_2O and the whole apparatus may be placed in a position so that the water will come in contact with the insulating material sheet which is held as a diaphragm between the bulb chambers. It is sometimes necessary to use rubber gaskets to make a tight joint between the sample and ground surfaces of the flanged side tubes.

The whole apparatus may be placed so that the water or water vapor in one bulb may come in contact with the diaphragm. Dry air is admitted each time a weighing is made.

Where rate of penetration of H_2O is small, and to eliminate the weighing errors, a pressure difference due to penetrated moisture is measured. In this case a trap attached to the lower end of the dry bulb is used to freeze out the penetrated water vapor. When freezing mixture is taken away the difference in pressure is measured by means of the optical manometer gauge designed by Shrader.[2]

An Improved Method of Analysis of Bearing Alloys and Similar Mixtures. (*Helvetica Chim. Act.*, vol. ii, p. 398, 1919.)—Osterheld and Honnegger describe a method which has given excellent results in their hands and which avoids the use of the more powerful oxidizing. The finely divided alloy is boiled with concentrated sulphuric acid. The procedure is applicable to alloys containing antimony, lead, tin, and copper. The finely divided material is boiled with concentrated sulphuric acid. Even alloys rich in lead are quickly dissolved. Antimony passes into solution as an antimonous compound, tin as stannic sulphate, copper and lead into the ordinary sulphates, which are partly soluble in the acid. By dilution the whole of the lead sulphate can be precipitated. The lead sulphate can be collected on a gooch filter and dried and weighed, the antimony determined by titration with potassium bromate, and subsequently the tin and copper determined also volumetrically. H. L.

[2] *Phys. Rev.*, vol. xiii, p. 321–25.

NOTES FROM THE U. S. BUREAU OF MINES.*

METALLURGY OF WULFENITE.

By J. P. Bonardi.

PROBABLY 90 per cent. of the molybdenum produced in the United States during the war period was derived from molybdenite, in spite of the fact that prior to 1915 the wulfenite ores of Arizona supplied the larger part of the molybdenum. This is because of the successful application of flotation to molybdenite and because the deposits of the latter are larger. The wet concentration of wulfenite ore offers little difficulty, but a number of associated minerals—vanadinite, cerussite, anglesite, galena, pyromorphite, and mimetite—come out in the concentrate, rendering its subsequent treatment somewhat difficult. Usually, a concentrate of 15 to 20 per cent. MoO_3 is the best that can be obtained, and buyers of concentrate frequently set the latter figure as their minimum content. Wulfenite has the advantage over molybdenite that it frequently has gold associated with it, and both this and the lead are recovered in the treatment of the concentrate. Any of three methods may be used: (1) an acid leach; (2) an alkaline leach; (3) fusing with something that will reduce the lead to the metallic form and take the molybdenum into the slag. The first has so many disadvantages compared with the other two as not to merit much consideration. Of the various alkalies, sodium sulphide is, perhaps, the most satisfactory, as the molybdenum goes into solution as sodium molybdate, while the lead and precious metals remain in the residues. This process is used by at least one company in the United States at the present time. The high-grade calcium molybdate thus produced can be used for the production of ammonium molybdate, ferro-molybdenum or added directly to the steel in the manufacture of alloy steels. By fusing with soda ash, caustic soda and coal, the lead is recovered in the form of bullion. The sodium molybdate thus formed can be leached from the slag and the metal precipitated in the form of calcium molybdate, which can be utilized as stated above. In one of the experiments a recovery of 96.7 per cent.

* Communicated by the Director.

was made on the molybdenum and of 98.5 per cent. on the lead, and it is estimated that a 90 per cent. extraction of both would represent commercial practice. At present prices there is a difference of $270 between the value of the products and the cost of the chemicals in treating a ton of typical concentrate, so that the process would seem commercially feasible.

MAGNESITE.

By W. C. Phalen.

RAW Austrian magnesite contains iron in natural combination. That produced in the state of Washington has a much lower iron content, and before calcining 2¼ per cent. iron oxide in finely divided condition is added to the ground and screened magnesite and the mixture is then calcined at a high enough temperature to thoroughly sinter the iron oxide. The resulting product is as good as the Austrian in every way and has been exclusively used by one of the principal American makers of magnesite refractories since the middle of 1918, nearly 60,000 tons having been used and marketed. About 10 per cent. of the magnesite produced in this country is used to make magnesite flooring, or oxychloride cement, the manufacture of which began in the United States about 20 years ago in an experimental way and for the past 6 or 8 years has been commercially successful. When magnesite is calcined at a temperature of 1600° F., it produces caustic burned magnesite, which reacts with peculiar phenomena with a solution of magnesium chloride, producing, when in combination with fillers, a tough, compact mass known as oxychloride or sorel cement. The resultant composition has strength sufficient to make a compact, resilient, and sanitary flooring which has extraordinary strength to withstand blows and rough wear, is tough enough to prevent the formation of cracks, and is impervious enough to withstand puncture. Unlike Portland cement, it is possible to saw, cut, and insert screws into it. The product also possesses fire resistance, and heat insulation. It has, therefore, been found useful in monolithic floors, in stucco, and slabs, for insulation and pipe covering, for the decks of ships, the floors of freight and Pullman cars, hospitals, etc. Its cost is slightly in excess of foundation cement, but well within the cost of other permanent floorings, such as tile, etc.

MINOR NOTES.

Sulphur in Coal.—A survey has been made of all present methods of removing sulphur from coal and its products. The substitution of Illinois coal for Eastern coke in the making of water gas in gas plants of the Middle West is greatly to be desired. The present gas-making equipment being designed for a non-volatile fuel, does not give as good results as may be expected on apparatus designed for bituminous coal. It appears that the design of such gas-making apparatus is largely empirical, and the Bureau will attempt to suggest a rational basis for the re-design of such apparatus for bituminous coal. The work, so far, appears very favorable.

Dust in Copper Mines.—The Bureau, in coöperation with the U. S. Public Health Service, has begun a study of dusts from the copper mines of Miami, Arizona. A volume of 19 cu. ft. of mine air is filtered through a glass tube containing 100 gm. of sugar, the tube being of such dimensions as to give a filtering column 1¾ in. high. The sugar is then dissolved in water and the recovered dust screened through a 280-mesh screen, which removes all particles larger than 50 microns in diameter. These are rejected, as particles of wet dust larger than 10 microns in diameter are considered harmless, since they do not lodge in the lungs. The dust is then graded into two portions, a non-injurious, consisting of particles between 12 and 50 microns in diameter, and an injurious, made up of particles smaller than 10 microns. Not enough samples have been analyzed as yet to give representative figures. The total dust will be determined in milligrams per cubic metre of air, the number of particles per cubic metre, the number of injurious particles per cubic metre, their weight in milligrams per cubic metre, and the weight of the dust over 10 microns diameter in mg. per cubic metre. Photomicrographs are also being made of characteristic dusts. The Bureau is also making a study of the concentration and nature of dusts in potteries, in coöperation with the Department of Labor. Samples are collected and the total weight of dust, total lead, and soluble lead determined. The soluble lead is determined by digesting the dust collected with a 0.25 per cent. solution of HCl., which takes into solution all the lead present as white or red lead, but does not act on the disilicate. The latter is considered harmless, as

it is not taken up by the human body. The investigation has, so far, shown that practically all the lead present in the glaze dusts is in the soluble form. A sample collected in a dipping room, while it was being swept, showed 47.9 mg. total dust, 8.7 mg. total lead and 8.7 mg. soluble lead. This represents very dusty conditions. Average figures per 100 cu. ft. of air collected in different rooms of potteries show from 2 to 100 mg. of total dust, and from 0.05 to 8 mg. of soluble lead.

Coal mine fatalities for the month of June showed a marked increase, compared with preceding months, due to the occurrence of an unusual number of explosions and other disasters.

All the new mine rescue cars of the Bureau have been accepted from the builders and put in use.

Photographic Records. (*American Machinist*, vol. li, No. 4, July 24, 1919.)—While the camera and a photographer have become a part of the equipment of many shops, we are not as yet utilizing them to their capacity. They are too often confined to making photographs of completed machines for publicity purposes when there are many other uses where they would prove most valuable.

During the war nearly every machine-building shop was very active in the Liberty Loan campaigns, as well as the Red Cross and other drives. Attractive decorations were used in many cases, and much time and effort were spent to make these campaigns fully successful. Yet for the most part, the only records of these activities now in existence are in the memories of those who participated in them, making it impossible to comply with a governmental request for such photographs to be used in showing the activities of the machine-tool industry in the great war.

Memory plays us so many tricks that photographs of even commonplace things are often found valuable in later years. Even general photographs of various shop departments, either at stated intervals or after each alteration or rearrangement of machinery, may readily bring out that which otherwise escapes attention and perhaps prevent changes which would simply be a return to conditions found unsatisfactory.

Interesting machine set-ups, unusual tool fixtures and guages, photographs of machine failures and similar subjects are all likely to prove of value as time goes on.

These and similar photographs are particularly valuable in organizations having a publication which reaches the employees of the plant. Photographs can also be made extremely useful as an aid in instructing workers either in the shop or training school.

THE FRANKLIN INSTITUTE.

MEMBERSHIP NOTES.

NECROLOGY.

Mr. Andrew Carnegie was born November 25, 1835, at Dunfermline, Scotland, and died at Lenox, Massachusetts, on August 11, 1919. He was brought to this country by his parents when twelve years of age, and settled at Allegheny City, Pennsylvania, in 1848. Two years later he became a telegraph messenger. He spent his spare time studying telegraphy, and was soon promoted to the position of operator. He then obtained a position with the Pennsylvania Railroad, and his advancement with this company was rapid.

About 1863 he organized the Keystone Bridge Company and soon after the Cyclops Mill. These were consolidated within a short time by the organization of the Union Iron Mills. Mr. Carnegie visited England in 1868 and while there investigated the Bessemer Process. On returning to this country he introduced the process in his mills.

After this he became principal owner of the Homestead and Edgar Thomson Steel Works and other large plants, as head of the firms Carnegie, Phipps & Company and Carnegie Brothers Company. In 1899 the interests of these various companies were consolidated under the name of the Carnegie Steel Company, which two years later was merged in the United States Steel Corporation, when Mr. Carnegie retired from business.

It would be impossible to give a detailed list of his benefactions and gifts, but the following are among the most notable: Carnegie Corporation of New York; Carnegie Foundation for the Advancement of Teachers; Carnegie Institute (Pittsburgh); Carnegie Institution of Washington; Carnegie Hero Funds; Endowment for International Peace; International Bureau of the American Republics.

During his lifetime he provided 2811 Free Public Library buildings, and contributed more than twenty millions of dollars to the colleges of the United States. He also made liberal contributions to organizations engaged in war work.

Mr. Carnegie was author of the following works: "An American Four-in-Hand in Britain," 1883; "Round the World," 1884; "Triumphant Democracy," 1886; "The Gospel of Wealth," 1900; "The Empire of Business," 1902; "The Life of James Watt," 1906, and "Problems of Today," 1909.

Mr. Carnegie became a member of The Franklin Institute in 1889.

Mr. John Sterling Deans was born at Chester, Pennsylvania, June 25, 1858, and died at Phoenixville, Pennsylvania, December 16, 1918. Mr. Deans' technical training was received at the Polytechnic College in Philadelphia. In 1879 he accepted a position with Clarke-Reeves & Company, which concern

later became the Phoenix Bridge Company. Thirteen years later Mr. Deans was made Chief Engineer, serving in this capacity until about three years ago, when he was appointed Vice-President and Consulting Engineer.

Remarkable developments in bridge construction occurred during Mr. Deans' career. Iron was gradually abandoned as the material for bridge building and replaced by steel. Mr. Deans was active not only as a designer and manufacturer, but also as a constructor of many notable structures: among these are the Ohio River bridges at Cincinnati and Louisville; Mississippi River bridges at Rock Island and Davenport; the cantilever bridge at Red Rock, Arizona; Kinzua and Pecos viaducts.

Mr. Deans was active in the development of the modern long span structure, and because of his unusual experience his counsel was frequently sought in connection with the designing of large steel bridges.

Mr. Deans became a member of The Franklin Institute on March 5, 1901.

Allen Eugene Nichols was born at Madison, Wisconsin, September 30, 1888, and died at Chicago, Illinois, on May 8, 1919. His early education was obtained in his native city, and in 1906 he entered the Civil Engineering Department of Purdue University, from which institution he graduated in 1910. Three years later the degree of Civil Engineer was conferred upon him by his *alma mater*.

On leaving college Mr. Nichols entered the employ of the Baltimore and Ohio Railroad Company. Some months later he was appointed an assistant to the Consulting Engineer for the State of Indiana, devoting his attention especially to the design of water works and sewage disposal plants. In April, 1911, he again became active in railroad work, and for more than a year served as Assistant Engineer on Track Elevation and Maintenance for the Chicago and Western Indiana Railroad Company. Later he became connected with a firm of consulting engineers, acting as assistant engineer of design and construction for sewage disposal and water supply plants. In February, 1914, Mr. Nichols entered the University of Pennsylvania as a special student, devoting his attention to the study of the chemistry of water. On completion of this work, in May, 1915, he was appointed one of the engineers for the Bureau of Waste Disposal of the city of Chicago, which position he held for nearly three years.

When the United States entered the war, Mr. Nichols joined the staff of the du Pont Engineering Company in the capacity of Engineer of Construction for a seventy million gallon water filtration plant for the Government powder factory, at Nashville, Tennessee. In February last, with his father and brother, he entered into the general engineering and contracting business. Mr. Nichols was a member of the American Society of Mechanical Engineers, the American Water Works Association and other kindred societies. He became a member of The Franklin Institute on March 14, 1917.

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CORRESPONDENCE.

UNITED STATES DEPARTMENT OF AGRICULTURE.
Bureau of Plant Industry.

WASHINGTON, D. C., July 30, 1919.

Dr. R. B. Owens,
Secretary, The Franklin Institute,
Philadelphia, Pa.

DEAR DR. OWENS:

Your letter of July 28th informing me of the awarding of the Edward Longstreth Medal of Merit for 1919, has been received. The medal and certificate also came promptly.

I wish to express my appreciation to The Franklin Institute for the honor conferred and take this occasion to thank you for this.

Yours very sincerely,

J. J. SKINNER,
Biochemist.

DEPARTMENT OF COMMERCE.
Bureau of Standards.

WASHINGTON, July 30, 1919.

Address reply to Bureau of Standards.

Dr. R. B. Owens, Secretary,
The Franklin Institute,
Philadelphia, Pa.

DEAR DR. OWENS:

Kindly bear to The Franklin Institute my heartiest thanks for the Edward Longstreth Medal and Certificate just received.

Yours very truly,

ENOCH KARRER.

DEPARTMENT OF THE INTERIOR.
Bureau of Mines Experiment Station.

GOLDEN, COLORADO, August 2, 1919.

Dr. R. B. Owens,
Secretary, The Franklin Institute,
Philadelphia, Pennsylvania.

MY DEAR DOCTOR OWENS:

I desire to acknowledge the receipt of the Edward Longstreth Medal, and also the certificate to accompany it.

I desire to thank the Committee on Science and the Arts and The Franklin Institute for the honor conferred upon me, and to express my appreciation of the award.

Sincerely yours,
R. B. MOORE,
Superintendent.

EASTMAN KODAK CO.

ROCHESTER, N. Y., August 4, 1919.

Dr. R. B. Owens, Sec.,
Franklin Institute,
Philadelphia, Pa.

DEAR SIR:

I have received the Edward Longstreth Medal and Certificate recently awarded me jointly with Doctors Ives and Karrer.

I wish to take this occasion to thank the Institue and its Committee on Science and the Arts for the generous award. I am indeed pleased to know that the results of our joint labors on the Welsbach mantel have merited this recognition and it is certainly a most happy termination of the work.

Again thanking the Institute most hearily, I remain

Respectfully,
EDWIN F. KINGSBURY.

BOOK NOTICES.

ONE THOUSAND TECHNICAL BOOKS. Compiled by Herbert L. Cowing. First Edition. 118 pages and index, 8vo, paper-bound. Washington, American Library Association, Library War Service, June, 1919.

The great increase of small libraries, whereof the chiefs and assistants are without technical training except in the specific field of library administration, has no doubt brought to the officers of the A. L. A. many requests for assistance in selections. Furthermore, the establishment of camp libraries with many patrons who had but limited technical training and desired more, compelled a selection of such works. With few exceptions the books chosen are of necessity of American origin, about half the list being credited to three New York City publishing houses. No two experts in any of the departments covered would be likely to agree throughout as to the selections, but in a

compilation of this kind, dogmatism cannot be avoided. The compiler may secure some assistance from experts, but must in the main be guided by the "inner light." The pamphlet represents a large amount of labor and will be of much aid along the lines for which it is prepared.

HENRY LEFFMANN.

LECTURE DEMONSTRATIONS IN PHYSICAL CHEMISTRY. By Henry S. van Klooster, Ph.D., Rensselaer Polytechnic Institute, 187 pages, illustrations, bibliography, index, 12mo. Easton, Pa., The Chemical Publishing Company, 1919. Price, $2.

This is a timely and interesting book. The literature of physical chemistry is immense and growing at a geometrical ratio, and while many illustrative experiments are detailed in the larger treatises, teachers of general chemistry, especially those who entered upon their work a generation or more ago, will find the collection of simple demonstrative methods very useful and convenient. Numerous illustrations aid in the construction and arrangement of apparatus. The author quotes Arrhenius to the effect that there are few departments of exact science in which so few lecture experiments are shown as in physical chemistry, and holds that this is due to the fact that so large a portion of the investigations is quantitative, while lecture experiments as a rule can only show qualitative changes. Doctor van Klooster also points out that many manuals of general chemistry spread the facts of physical chemistry over the whole of the descriptive text. Thus, adsorption is discussed in connection with charcoal, colloids with silicon, allotropy with oxygen. The book in hand is written in opposition to this plan. The classification is by type of phenomena, not by substance.

One of the most interesting chapters is that on Actino-chemistry. A number of very interesting experiments have been collected. The subject of flame, combustion and explosion is also interestingly treated. Another useful chapter is that on catalysis, but it is too brief.

The book is well printed, the type being that now so familiar to American chemists through the publications of the Easton firm. A few typographic errors have been noted, but are mere slips of the compositor and not misleading. The paper is not as good as it ought to be. It is to be hoped that the present edition will soon be exhausted and that the author will find time to prepare a second one on a much larger scale.

HENRY LEFFMANN.

CURRENT TOPICS.

Protection of Silvered Surfaces. F. KOLLMORGAN. (*Journal of the Optical Society of America,* January–March, 1919, p. 16.)—At the commencement of the European war the importation of optical glass stopped completely, and at that time no glass suitable for optical instruments was being manufactured in this country. While it appeared probable that before long the glass industry of the United States would be in a position to turn out the ordinary kinds of optical glass, such as crown and flint, it was doubtful how long it would take before the considerable difficulties attending the manufacture of the more modern varieties of glass, such as the borosilicate crown and baryum crown, would be solved. Being engaged in the manufacture of periscopes for submarines, in which eyepiece reflectors of considerable size are used, the writer foresaw serious trouble unless some reflector could be developed which could take the place of the borosilicate prisms so far employed for that purpose. A plain glass mirror, silvered at the surface, of course, presented the easiest solution provided the surface could be protected efficiently against atmospheric influences. While looking up the subject of the possibility of such protection which, of course, must not, in any way, interfere with the optical efficiency of the mirror, it was found that as late as 1894, Mr. Izarn published in the *Comptes Rendus* a protective coating of bichromated gelatin which he had applied on a 33-centimetre telescope reflector at the Toulouse Observatory. This reflector withstood the influence of sulphuretted hydrogen for twenty-four hours without change. In 1909 Mr. A. Perot described also in *Comptes Rendus* a protective coating consisting of celluloid dissolved in amylacetate. Mr. Louis Bell in the *Electrical World,* 1913, mentions the employment of a commercial lacquer sold under the name of Lastina Lacquer for the same purpose with very good results. It appears that a two-foot parabolic reflector used at the Harvard Observatory protected in this manner, lost only 4 per cent. of its original light transmission through the lacquering, and after three months service still retained 70 per cent. of its original light transmission.

Both Mr. Perot's and Mr. Bell's papers, however, state that the lacquer must be used in a very thin layer and will show interference colors. The first experiments made by the writer produced an efficient protection, but it was found that the interference colors showed plainly when the eyepiece was used on a periscope and this phenomenon had to be overcome. When the coating of lacquer was sufficiently thick to show no interference colors the lacquer dried sometimes in waves and streaks, and sometimes with a crinkly sur-

face seriously damaging the definition of the mirror, and it occurred to the writer that this appearance might be avoided by centrifuging the mirror during the drying so that the surface would be kept under an even tension until dry. An experiment along these lines proved very satisfactory and mirrors protected in this manner have been used since in a large number of periscopes with very good results. Even after a year's use the mirrors have shown no appreciable decrease in efficiency and no appearance of tarnishing whatever. The reflecting power of these mirrors is greater than that of a prism, for in some of our periscopes we have employed a mirror at the top for the high power and a prism for the low power and the increase in light transmission from low to high power has been quite noticeable. Owing to the rush of war work, it has unfortunately been impossible to make exact measurements of the light transmission.

The protection given by the coating of lacquer, is, however, a very slight one against mechanical damage, as the lacquer is very soft and will scratch at the slightest touch. If dust should settle on the mirror it must be removed by means of a very fine camel's-hair brush; a soft piece of chamois leather may be employed if care is taken that it is absolutely free from grit or dust. Attempts to harden the lacquer by baking have not proved successful. Various other lacquers and varnishes that were tried did not give as good optical results as the Lastina lacquer. Mr. Bell's paper suggests that lacquer should be thinned down in proportion of one part lacquer to six parts commercial thinner. We use one part lacquer and two parts thinner with our method.

Electrical Distribution in Mines. E. STECK. (*Coal Age*, vol. xvi, No. 1, July 3, 1919.)—The bituminous mines in the central states have a general practice of connecting the entire electrical distribution system underground to a circuit breaker on the surface. This practice has a number of shortcomings. If the circuit breaker trips all the locomotives, cutting machines and other motors are stopped. As soon as the breaker is put in all the motors are thrown on the line, creating a heavy overload on the power-plant equipment. All the machinery below is idle while the circuit breakers are out.

When heavy grounds occur there is no indication of their location. The entire mine is idle until the trouble is found and that section in which the short has occurred is cut off, or the trouble remedied.

By the use of circuit breakers underground trouble can be located much quicker. Only a small portion of the mine will be idle at such times and the starting over-load on the plant will be greatly reduced. Take, for example, a mine having two main entries: A switchboard panel can be placed on the bottom with two circuit breakers and switches, each controlling one-half of the mine. The lights on the bottom can be connected in behind

the circuit breaker so that no matter which breaker trips the lights will still be in service. The circuit breakers should be of the switchboard type. This makes each half of the mine independent of the other. This scheme can be further carried out by the location of railway-type circuit breakers at convenient places back in the mine. With such a layout in case of trouble a small part of the mine only is effected and the difficulty quickly located, as it must be behind the circuit breaker which has opened.

The small breakers pay for themselves in a short time because of the shorter shutdowns and the lower number of locomotives and machines affected. The wear and tear for this reason is not so great on the power-plant equipment. If power is purchased, especially where the maximum demand charged is based on short-time peaks, a decided saving in the power bill can be made because all of the equipment cannot then be thrown on the line at once after the main circuit breaker is closed on top.

Gas-masks for Protection in Industries. (*Journal Industrial and Engineering Chemistry.*)—The Gas-mask Research Division of the Chemical Warfare Service has called attention to the value of the army gas-mask in many industries in which offensive or poisonous gases are produced. As is well known, the United States chemists brought the gas-mask to a high degree of efficiency. The principal contents were charcoal and soda-lime in granules ranging between 8 and 14 mesh. This filling stopped chlorine phosgene, chlorpicrin, nitrogen oxides and some other gases; for gasoline, benzine, carbon disulfide, carbon tetrachloride, cyanogen bromide, and some other vapors not acted on by soda-lime, the charcoal filling alone will suffice. For acid vapors, and some acid anhydrides (*e.g., sulphur dioxide*) soda-lime alone was used.

When smoke particles, such as the hydrolysis products of stannic chloride, or solid particles, as arsenic trioxide, are encountered, the canister should contain at least two cotton wadding pads or other filter material.

Ammonia is not completely absorbed by the standard filling. For this purpose copper sulphate on pumice is recommended.

In considering the use of gas-masks for protection against various gases it must be emphasized that they should never be used in atmospheres containing less than 12 per cent. oxygen by volume. In such atmospheres an air helmet or a self-contained breathing apparatus containing an oxygen supply must be used. Neither does the army gas-mask afford complete protection against very high concentration of toxic or irritating gases, such as may be found in closed tanks or towers containing volatile liquids or in small closed rooms where a considerable quantity of gas has been suddenly released. In general, the gas-mask is limited to concentrations not exceeding 1 to 5 per cent., depend-

ing on the kind of gas, the absorbent used, and the size of the canister.

The standard canister containing filter pads gives good protection against smoke from wood, rags, tar, sulphur, and other combustibles. Tests have been made in which men wearing standard army masks remained in dense smoke from burning wood and wet straw for a period of twenty minutes without discomfort. Care, however, must be observed that such combustion smoke contains no appreciable quantities of carbon monoxide, for which the mask provides no protection, and which would not be detected by the wearer before being overcome. For this reason the standard army gas-mask with charcoal and soda-lime canister containing filter pads should be used with some caution by firemen in entering burning buildings; in exceptional cases, dangerous quantities of carbon monoxide may be present.

The army mask has been used successfully in fighting forest fires. It can probably be used safely in similar smoke occurring in the open air, or for a very short period of time in buildings where the smoke is diluted by air. H. L.

Gluing Wood Coated with Varnish or Shellac. (*Technical Notes,* Forest Products Laboratory, Madison, Wisconsin.)—Glue joints between wood surfaces which have been coated with shellac or varnish have low or very erratic strength. This has been thoroughly demonstrated by a recent test at Forest Products Laboratory, Madison, Wis. Sixty pairs of test blocks were prepared in which one or both wood surfaces were varnished or shellacked and were joined with either casein or animal glue. A great many of these blocks fell apart before testing and all which held together long enough to be tested sheared apart in the glue joint and not in the wood.

The highest strength value obtained was 1712 pounds per square inch, which is low for casein glue. The other values were 1000 pounds per square inch or less. It is evident, therefore, that all shellac or varnish should be carefully cleaned from wood which is to be glued, if high strength is desired.

A few blocks were joined using shellac as a glue over surfaces previously coated with shellac. The maximum shear strength obtained was 1425 pounds, the minimum 450 pounds, and the average 758 pounds per square inch. These values are low and do not indicate that shellac has gluing properties which compare favorably with casein or animal glue.

"American Storax" from the Red Gum Tree. (*Technical Notes,* Forest Products Laboratory, Madison, Wisconsin.)—A gum which is in demand by the manufacturers of perfumes, tobacco, adhesives, and pharmaceutical preparations, is produced by the red gum tree (*Liquidamber styraciflua*) of the south, though few owners

of this tree apparently are yet aware that the gum has any commercial value. The properties and composition of this "sweet gum," as it is called, are similar to those of oriental storax, obtained from a tree (*Liquidamber orientalis*) which grows in Asia Minor. Cinnamic acid and cinnamic alcohol are two of its valuable components.

Because the war curtailed the supply of the imported product, the U. S. Forest Products Laboratory this season undertook some coöperative experiments to develop methods of gathering "sweet gum" or "American storax." Although the yield of gum from each tree is not large, a price of $2 or more a pound has made its collection attractive to many individual operators and a considerable quantity has been put on the market.

The laboratory experiments will be completed in November, and it is hoped that they will provide some cost data which will indicate to what extent "American storax" can profitably compete with the foreign product when normal conditions return.

Detection of Dulcin and Saccharin by Optical Methods. A. ABRAHAM. (*Mem. Acad. Roy. d. Sciences de Liége*, vol. x, p. 4.)—Dulcin and saccharin are liable to be used in many beverages as substitutes for sugar. They are usually detected by color tests, but the author of this paper gives an account of their detection by the microscopic examination of the crystals from an ether-solution. These optical methods are becoming of increasing importance. They depend on the use of modified light, especially polarization. Very small crystals can be identified accurately. The method, as is well known, has been long applied in mineralogy in the examinations of rock-sections. The microscopic equipment is complicated and expensive. The United States Department of Agriculture is conducting special researches along this line, especially in connection with the detection of the alkaloids. H. L.

The Production of Large Perfect Crystals. R. W. MOORE. (*J. Am. Chem. Soc.*, vol. xli, p. 1060, 1919.)—After briefly reviewing the literature of the subject, describes a method by which very large and perfect crystals can be obtained from solution. It is well known that many fine crystals are found in nature, but these are usually so involved in the matrix as to prevent separation without injury and are often unequally developed in some planes. Moore required some perfect crystals of sodium-potassium tartrate and searched through several tons of the salt finding but little material. After examining the published methods, he devised a plan by which a saturated solution of the substance is made at a temperature between 35° and 40° C. This is heated a few degrees higher and then filtered. The temperature must be kept slightly above the saturation temperature. Small crystals of the salt, termed "seed-crystals," are placed in a jar, the solution

poured in the jar covered and placed in a large water-bath which is at a temperature of about 0.5° above the saturation temperature of the solution. The temperature is allowed to fall practically to the saturation temperature of the solution. By means of a sensitive thermostat the temperature is allowed to fall about 0.1° per day until the crystals have increased notably in size, and have formed perfect crystals. This usually takes a short time. The temperature is then allowed to fall 0.2° per day. When the crystals are nearly an inch long the rate of cooling is increased to about 0.4°, and when they are well over 1 inch to 0.6° per day. The thermostat setting is changed twice each day, morning and evening. When the solution has cooled to room temperature the crystals are taken out and wiped with a soft dry cloth. A photograph is given with the article showing some very fine crystals of sodium potassium tartrate produced by this method. The process is slow—to produce perfect crystals three inches long requires about one month. They are, however, well worth the trouble. Success depends, of course, largely on steady, slow cooling. Only when a condition of slight supersaturation is maintained does the crystal grow perfectly clear.

H. L.

The Insulating Properties of Erinoid.—Erinoid is a product of the action of formaldehyde on milk proteins. Casein products as substitutes for ivory, bone and similar substances have long been known. The best methods for their production were due to Swiss and German chemists. The war deprived British markets of the supplies, and British chemists took up the matter with the result of obtaining an excellent material to which the above name was given. Its insulating properties have been subjected to a careful examination by R. G. Allen, B.Sc., whose methods and results have been set forth in the *Scientific Proceedings of the Royal Dublin Society* (vol. xv, p. 331, 1919). The summary of experiments is as follows:

1. When dry, erinoid is a good insulator of fairly constant insulation resistance. It is slightly hygroscopic, but not so much as fibre.

2. Erinoid does not absorb water when in direct contact with it so readily and to such an extent as red fibre, neither is it so retentive of the water absorbed as the latter.

3. When its surface is not machined its resistance greatly depends upon the value of the applied voltage, unless water electrodes are used. This dependence is very slight in the case of unmachined fibre, whether mercury or water electrodes are used. In the case of machined erinoid the resistance is almost independent of the voltage.

4. It is practically free from dielectric absorption, but the latter is appreciable in the red fibre.

5. The relation pointed out by Rasch and Hinrichsen between temperature and resistance is true for erinoid and fibre.

6. Of the varieties of erinoid tested, red is the most absorbent of water and generally of the lowest resistance.

7. Erinoid of blonde color has a considerably larger resistance than the other varieties tested: probably due to greater skin or contact resistance.[1]

8. The specific resistance of erinoid diminishes with the thickness of the sample.

9. The break-down voltage of erinoid and fibre is practically the same. H. L.

Largest Aircraft Engine. (*Power Plant Engineering*, vol. xxiii, No. 14, p. 634, July 15, 1919.)—Marked progress is being made in the design of internal combustion engines to keep pace with the ever-increasing size of aircraft. Undoubtedly the largest aircraft engine which has been developed, to date, is the 850-h.p. Duesenberg motor. It has 16 cylinders, 6 by 7½ in., in two rows of eight each set in "V" form at an angle of 45 deg. With gear drive, the weight is 1575 lbs.; without gear drive, 1390 lbs. On direct drive, the speed is 1500–1600 r.p.m.; and with gear drive, the engine speed is 1800; propeller 1200–1350 r.p.m. Based on the lower rating and direct drive, the weight of the engine is 1.63 lbs. per h.p., a remarkably low figure for an engine of this type.

Three valves are provided on each cylinder, a 2⅝-in. inlet valve and two exhaust valves, each 2 in. in diameter. The intake valve is located above the exhaust valves, and by this plan the exhaust valves are cooled by the incoming mixture and the mixture itself is slightly warmed. Valves are operated by means of long rocker arms from a single cam shaft. This cam shaft is $^{13}/_{16}$ in. in diameter with ¾-in. hole, and is 70⅝ in. long. The 48 cams are forged integral with the shaft. Two short exhaust pipes per cylinder of 2-in o.d. tubing are provided. Gas is provided by four carburetors, and ignition by means of two magnetos. The propeller shaft is geared to the crank-shaft in the ratio of 2 to 3, running at 1200 r.p.m.

Cam-shaft and rocker-arm actuating mechanism are enclosed in a dust-proof housing, and to this mechanism oil is fed under pressure. Rocker-arm bearings are of special bronze, and the cam-shaft bearings are of aluminum with babbit liners. Connecting rods are of the straight and straddle type, fitted with bearings of special bronze. Pistons are of special aluminum alloy, and each has but one ring. They are heavily ribbed inside, 5¼ in. deep and have 1½ in. piston pins.

Cylinders are made from pierced forgings of chrome-nickel steel. The cylinder head is composed of steel stampings which are first welded together, then screwed into the cylinder, and afterward welded to the cylinder. The water jacket of stamped sheet steel is

[1] This was definitely shown, later, by testing machined blonde erinoid and finding it had practically the same resistance as black and red erinoid.

welded in position. The crank-shaft is 2⅞ in. in diameter and has a main bearing between every other pair of crank-pins. Oil is forced through the shaft under heavy pressure direct to all bearings, including those of the connecting rod.

Of the barrel type, with dry sump oil pan, the crank-case is fitted with strainers at each end so that the oil will flow to the pump regardless of the angle of flight.

Industrial Uses of Soya Bean Oil.—The soya bean is the seed of a plant native to northeastern Asia. Although practically unknown in this country before 1908, very large shipments have been made to Europe and America in recent years. The crude oil obtained by expression may be purified by sodium hydroxide as in the case of cottonseed oil, and then constitutes a valuable food oil. In a cruder form it is a drying oil, and owing to this quality has become a staple of the paint trade. Henry A. Gardner, Director of the Scientific Section of the Paint Manufacturers' Association of the United States, discusses the matter in Circular 67 of the Educational Bureau of that association. Soya oil cannot be used wholly in place of linseed oil on account of the feebler drying powers of the former, but may be used to the extent of about 50 per cent. In such large admixture, driers must be added. Gardner made a study of proposed driers, and finds that when properly selected the drying power of the soya oil is very high. Linoleates are the best salts. Cobalt and manganese salts have a tendency to produce hard films; lead and zinc salts produce somewhat elastic films. A combination of the two sets will, therefore, be best. The following formulas are given:

Manganese linoleate containing ..... 0.03 per cent of Mn.
Lead linoleate containing ..... 0.20 per cent. of Pb.
Cobalt linoleate containing ..... 0.01 per cent. of Co.

and

Lead linoleate containing ..... 0.20 per cent. of Pb.
Cobalt linoleate containing ..... 0.02 per cent. of Co.

The cake and meal after the extraction of the oil are suitable as stock-food and fertilizer.

As the plant is a native of a region in which the climate conditions closely resemble those of some portions of the United States, the cultivation of it in this country will probably be successful. Especially in those sections of the South in which the boll-weevil has exterminated cotton-raising, the cultivation of this plant may be useful, as the cotton-seed mills are well adapted for the crushing of the soya bean. Crude soya oil is also useful in the manufacture of soap. H. L.

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